HSE
Health & Safety Executive

Effective design and management of firedamp drainage

Prepared by
Wardell Armstrong
for the Health and Safety Executive

CONTRACT RESEARCH REPORT

326/2001

HSE
Health & Safety
Executive

Effective design and management of firedamp drainage

Dr David P Creedy
BSc (Min Geol), MSc, PhD, CEng, FIMM
Wardell Armstrong
Lancaster Building
High Street
Newcastle-under-Lyme
Staffordshire
ST5 1PQ

This research project was commissioned by the Health and Safety Executive (HSE) following a submission by Wardell Armstrong to the 'Competition of Ideas'. The work was undertaken between 1 November 1999 and 30 September 2000.

The principal aims of the research project were to review the state-of-the-art of firedamp drainage and its application in UK coal mines, and to provide recommendations to HSE's Mines Inspectorate on safety enhancements relating to firedamp drainage.

The work programme included a worldwide literature review, visits to selected UK mines and discussions with HSE's Mines Inspectorate. Emphasis was placed on using observations and discussions at mines, together with findings from the literature review, as a basis for developing practical guidance for application in UK mines. The handbook, presented in Annex 1, is intended to promote effective firedamp drainage management and is structured in accordance with current HSE thinking on safety management processes. Details of the background studies are recorded in the body of this report. Technology gaps are identified and recommendations made for future research which could produce significant practical benefits to firedamp drainage operations.

The anticipated benefits of the project are an improved understanding of the fundamentals of firedamp drainage in UK coal mines and safer working conditions in gassy coal mines.

HSE BOOKS

First published 2001

ISBN 0 7176 1967 2

Executive Summary

A worldwide review of firedamp drainage methods, and recent research, has been undertaken. Practical information pertinent to the UK was obtained by visiting Maltby, Thoresby, Welbeck and Kellingley collieries. Findings at these sites, combined with results of studies at Tower colliery, have been analysed to provide the basis for a best practice guidance document on firedamp drainage design and management (Annex 1).

Firedamp drainage needs in UK mines can be satisfactorily met with currently available equipment. However, there is scope for improvement in gas drainage efficiency through more effective firedamp drainage management. Further research into strata support at return face-ends is also needed to enable drainage borehole performances to be improved.

CONTENTS

1. INTRODUCTION

Firedamp drainage techniques allow planned coal production rates to be achieved safely by reducing gas emissions into longwall mining districts to a flow that can be satisfactory diluted by the available fresh air. In some instances gas drainage is also needed to reduce the risk of sudden, uncontrolled emissions of gas into working districts.

The safety of underground operations at most collieries in England and Wales is dependent on the effectiveness of firedamp drainage. The consequences of failure or performance inadequacies are potentially hazardous working conditions and an increased explosion risk. Practical difficulties can be reduced by good planning which requires a sound understanding of the basic scientific and engineering principles. These principles are based on the results of research undertaken during the past 60 years to develop an understanding of the emission behaviour of gases in coal seams and the methods used to control them.

All UK mines with firedamp drainage use a cross-measures drilling method which was developed in Germany more than fifty years ago. Boreholes are drilled at an angle above, and also in some instances below, the goaf. The boreholes are drilled close to the coalface and linked to a common pipe range. Suction is applied to the pipe range from either surface or underground pumps to draw the gas to a discharge point or firedamp utilisation plant. Sufficient air is passed around the mine district to dilute gas, which is not captured by the firedamp drainage system, to a safe level together with the gas emitted from the worked seam itself.

The cross-measures method of drilling involves undertaking drilling operations near to the coal face where working room is limited and high temperatures and gas concentrations can arise. Firedamp drainage activities therefore need to be carefully managed to ensure that personnel are not exposed to unacceptable environmental conditions and health and safety risks.

2. BASIC PRINCIPLES

The performance of a firedamp drainage scheme at a coal mine depend on a wide range of factors. A rational approach to the design, implementation and management of a scheme can only be made if these factors and the underlying principles are understood.

A necessary first step is a basic understanding of:

- The occurrence and measurement of methane in coal seams
- Firedamp emission processes in coal mines
- How firedamp is captured from the strata around underground mine workings
- How firedamp is controlled to ensure safe working conditions

2.1 FIREDAMP AND ITS OCCURRENCE IN COAL SEAMS

The gas found naturally occurring in coal seams is known as firedamp or coalbed methane (CBM). The principal constituent of firedamp is methane (typically 80% to 95%) with lower proportions of ethane, propane, nitrogen and carbon dioxide. As methane is the predominant constituent of firedamp, the two terms are used interchangeably for practical coal mining purposes. The mixtures of firedamp, water vapour, air and associated oxidation products which are found in coal mines are usually collectively termed "mine gas."

Firedamp was formed in coal seams as a result of the chemical reactions taking place as the coal was buried at depth. The greater the temperature and duration of burial, the higher the coal maturity (rank) and hence the greater the amount of gas produced. Much more gas was produced during the "coalification" process than is now found in the seams. The lost gas has been emitted at ancient land surfaces, dissipated into the pores of surrounding rocks, removed in solution, and some will have migrated into reservoir structures. Nevertheless, original gas content patterns tend to be preserved following similar trends to coal rank.

In a vertical sequence of coal seams, methane contents often show a systematic increase with depth. For example, in the Nottinghamshire coalfield, methane contents typically increase by $0.006m^3/t$ for each meter increase in vertical depth. In contrast, gas contents of seams in the South Wales coalfield show a systematic variation laterally with coal rank but do not change significantly with vertical depth other than close to the surface. Such observed relationships are useful when allocating gas contents to a sequence of coal seams in gas emission prediction calculations.

Firedamp can be detected in many sedimentary rocks but generally only in low concentrations. It occurs in much higher concentrations in coal rather than in any other rock type because of the "adsorption" process which enables methane molecules to be packed into the coal substance to a density almost resembling that of a liquid.

2.2 SEAM GAS CONTENT AND ITS MEASUREMENT

The gas content of a coal seam is expressed in units of meters cubed of methane per tonne (m^3/t) of ash-free coal. If gas content values are not available for a particular underground site, then measurements can be made on coal samples taken from underground boreholes, driveages or coalfaces.

There are two basic methods for measuring the gas content of coal seams, namely the "Statistical" method and the "Desorption" method (Creedy 1986).

2.2.1 The Statistical Method

The Statistical method involves taking fresh coal samples from coalfaces or driveages and measuring their gas contents. Some samples will have lost more gas than others before sampling, therefore a spread of gas content values is expected. Samples with the highest measured gas contents represent coal which has lost the least gas. By fitting the data to a suitable statistical distribution, the initial gas content of the seam can be estimated.

2.2.2 The Desorption Method

The Desorption method requires cores to be taken from coal seams that have not been sufficiently disturbed by mining to lose any gas before they are sampled. There are many experimental variants of the method. The general principle involves measuring the rate of gas emission from a sample and using the result to estimate gas losses which occurred during the coring and sampling processes. The gas remaining in the sample is released by crushing and the concentrations of its constituents determined by laboratory analysis.

The Desorption method was designed to obtain seam gas contents from measurements on coal cores from vertical surface or underground exploration boreholes. Nowadays, exploration drilling is limited so gas content measurement usually relies on face sampling.

2.2.3 Seam Gas Content Data

The Coal Authority has inherited a seam gas-content database produced by the former British Coal to which access can be provided. Gas content values can be estimated by interpolation from these data.

Gas contents of coal seams currently being worked in the UK range from less than 1 m^3/t up to around 15 m^3/t.

2.3 FIREDAMP EMISSION IN COAL MINES

Deep coal in the UK is generally extracted by means of a retreat longwall mining method typically involving two parallel access roads, up to some 300m apart, linked by a mechanically supported coalface.

Firedamp is emitted from the coal exposed on the coalface, coal broken by the cutting machine and coal on the conveyors. As each strip of coal is removed, and the face supports are moved forwards the unsupported area (‘waste', `gob' or `goaf') left behind collapses. A consequence of the caving is that seams above and below the worked horizon are also disturbed and release gas. As much as 90% of the firedamp entering a longwall district may come from adjacent seams and the remaining gas from worked seam sources. The faster the coal is extracted, the higher the firedamp flow into the district.

In addition to the gas released from coal seams, gases can also be released from conventional sandstone reservoirs when they are disturbed by mining activity. Gas can also be introduced onto a district in the ventilation air when outbye sources of pollution, such as old workings in the intake, are present. Series ventilated developments situated on the intake side of the mine may also cause pollution to working panels.

Emissions from old workings are usually exacerbated by rapid falls in barometric pressure. Effects can be reduced by application of ventilation and gas drainage controls. Gas pressure in stopped-off districts on intake laterals is sometimes reduced by installing drainage pipework into the return airway, thus minimising intake pollution. Main mine ventilation is usually an exhausting system so that if it was interrupted, ie. the surface fan stopped, then the pressure in the mine would rise and thus inhibit the migration of firedamp from abandoned parts of the mine into the airways.

A specific emission (with the same units as gas content) can be calculated which represents the volume of firedamp released into the mine per tonne of coal mined. Specific emission can be calculated for a specific coalface district or for a whole mine. Gas flows from seams above and below the workings do not respond immediately to changes in coal production rate, building or decaying gradually when production rises or slows. To obtain a reasonable estimate of specific emission, flow data therefore need to be averaged over a long period of time (at least a few months, ideally a year). Specific emission is a useful, although fairly crude, indicator of the gassiness of a particular district or colliery. Values do not appear to be readily available for most UK mines.

Coal seams in Britain, are generally of low permeability. Confirmation of this is provided by the low rates at which firedamp flows into development driveages driven into the solid coal. Gas will, therefore, only flow if the coal is disturbed, either geologically or by mining. The retention of relatively high gas contents in sample lumps of coal that can often be removed from coalfaces is also indicative of low permeability. This means that gas does not generally flow readily from coal seams unless they are disturbed and fractured by mining activity.

2.4 GAS RELEASE PROCESSES

Longwall caving can theoretically de-stress strata from 160m to 200m above and down to 40m to 70m below the worked seam. Any gas sources within the disturbed zone will release a proportion of their gas which will flow towards the workings. The extent of the disturbance may be reduced where strong beds are present in the strata. Seams lying 40m or more below longwall workings do not always release significant gas flows.

The extent of the zone disturbed by longwall mining, at a particular location, depends on the length of the coalface, the height of the coalface, the strata strength, the depth of working and effects of previous workings.

In virgin strata, where longwall coal faces are less than 250m in length, the de-stressed zone in the roof may not extend as high as 200m. Progressively shorter coalfaces will produce correspondingly smaller heights of de-stressed strata in the roof. The volume of gas released when the coal is worked will, therefore tend to decrease per tonne of coal mined due to the smaller number of coal seams disturbed. This effect is likely to be most noticeable where there are strong beds in the roof. Currently, virgin working is practically limited to parts of the Selby coalfield.

Coalfaces are sometimes planned so they are separated by substantial coal pillars to ensure that strata movements caused by working do not create difficult ground stability problems on the next coalface, worked alongside. Other mining and geological circumstances may allow total extraction). Where total extraction ("skin to skin" working) is practised, or where an overlying seam has been previously worked de-stressed zones usually develop to the full height, irrespective of face length, once the first panel has been worked out. The gas flow per tonne of coal mined is not usually greatly affected by the presence of coal pillars between successive longwalls where longwalls are 200m or more in length, other than where exceptionally strong beds in the roof strata reduce the height of de-stressing.

The rate of gas flow into a particular mining district depends on the gas contents, number and thicknesses of seams in the disturbed zone, the proximity of the seams to the worked seam, the age of the district and, most importantly, the rate of advance or retreat.

The gas flow on the coalface correlates closely with the coal cutting activities but the emissions from seams above and below the workings depend not only on the current day's retreat rate but also on that of previous days. This occurs due to the cumulative effect of progressive disturbance on gas emission.

2.5 CONTROL OF FIREDAMP IN COAL MINE WORKINGS

In its naturally occurring state in a coal seam, firedamp does not constitute an explosive risk. However, where firedamp released from adjacent seams meets "fresh-air" in the goaf, the firedamp is diluted and explosive mixtures (around 5% to 15% methane in air) are formed.

Effective firedamp control is essential for safe working and involves providing either:

- Sufficient air to dilute and disperse firedamp at all levels of planned coal production; and, if necessary
- Sufficient firedamp drainage to ensure no more gas enters the mine airways than can be diluted to below statutory limits by the available ventilation air

2.5.1 Face-End Ventilation and Gas Control

On retreat coalfaces, special face-end ventilation arrangements are essential to ensure that these potentially explosive mixtures are kept well back in the goaf and away from coalface operations. Air from the face is diverted along the waste edge a distance of some 10 to 20m before it is allowed to pass onto the rib side and flow into the return. The pressure gradient thus formed prevents high gas concentrations in the goaf from migrating towards the face-end. This arrangement is formed by either constructing a curtain in the return roadway or leaving a narrow coal pillar at the face-end. Most retreat faces in the UK use prefabricated curtains.

2.5.2 Firedamp Drainage on Retreat Longwalls

On an advancing coalface, firedamp drainage boreholes are drilled above the goaf from the return roadway just behind the face line. As the face advances more boreholes are added. On a retreating coalface, boreholes are usually drilled behind the face line where special support and ventilation arrangements are needed to enable the firedamp drainage boreholes to be drilled safely. Poor roof conditions, or floor lift behind the face can create access difficulties and seriously delay borehole installation. To reduce the access problem and ensure a safe drilling environment, boreholes are sometimes drilled from the return roadway before the face passes. Limited success has been achieved with pre-drilling but consistency of capture and high capture efficiencies are rarely achieved due to the effects on the boreholes of high stresses around the face area.

Firedamp capture efficiencies on longwall faces typically lie between 60% and 80% of the total gas on advancing faces and from 30% to 60% of the total gas on retreat faces. Lower captures tend to be achieved on retreat faces compared with advancing faces because the producing boreholes cannot always be monitored, adjusted or maintained once they are more than 15 to 20m behind the face. In contrast, all the boreholes on an advancing face remain accessible and available for the full life of the district.

2.5.3 Alternatives and Supplements to Firedamp Drainage

There are ventilation options applicable to some retreat longwall coalfaces which can obviate the need for costly firedamp drainage. Such methods (eg. bleeder roads and sewer gate systems) are aimed at diverting gas away from working coalfaces along routes separate from those used to service the face.

To form sewer gate or bleeder road systems, the starts of retreat longwall faces are connected across coal pillars with roadways leading to the return airway where the gassy air can be discharged.

A bleeder arrangement involves maintaining a roadway alongside the gob in which the ventilation air leaves the district together with gas emitted from the goaf. Sufficient ventilation air must flow in the bleeder road to dilute the gas to a safe concentration (less than 2%) to enable the roadway to be inspected and maintained.

A sewer gate system typically involves an abandoned roadway into which the high concentration firedamp from the goaf, behind the coalface, is diverted by ventilation pressure (the aim being a high pressure gradient and low flow). Only a small proportion of the district airflow passes behind the face, most of it returning along one of the access roadways. The gas is thus prevented from migrating into the air circulating around the coalface district. As the abandoned road does not have to be travelled, there is no statutory limit to the concentration of firedamp carried. The system is arranged to discharge into a return airway where the gas is rapidly diluted to an acceptably low concentration.

A sewer road system requires careful planning, monitoring and regulation to work effectively. Sewer roads are not suitable for use in seams which are liable to spontaneous combustion.

The maximum total coalface district methane flow with a sewer or bleeder road system is:

$$T_s = (100(Q-q)/b(100-D)) + 10qC$$

Where q is the airflow (m^3/s) diverted into the sewer or bleeder road and C the methane concentration at discharge. For a bleeder road, q will be relatively high and C low; the opposite being the case for a sewer gate.

An increase in the coal production limit is only achieved once the firedamp concentration attained in the sewer road exceeds the statutory limit allowed in the district return.

2.5.4 Goaf Flushing

Goaf flushing has been used for temporarily amelioration of firedamp concentrations in a district return but it is not a recommended gas control solution.

The method is generally applied to a fully-developed goaf (ie. where sufficient goaf has been created to form a substantial gas reservoir). The ventilation pressure across a district is reduced, after men have been withdrawn, allowing high gas concentration gas to migrate forward into the return airway. Transport activities in the main return may have to be suspended. Eventually, the equilibrium between gas flow into the waste and gas flow into the return is restored, the gas concentration in the district return being at a higher concentration than before due to the reduced air quantity. On restoring the original airflow, the gas is forced into the goaf, away from the face, thus reducing the emission into the return until equilibrium conditions are once again obtained.

This approach is not advised due to the uncontrolled release of elevated firedamp concentrations into airways and across electrical equipment.

3 DESIGN OF FIREDAMP DRAINAGE SYSTEMS

Firedamp drainage requirements are determined on the basis of expected firedamp emission rates. The likely variability in gas flow and quality can be obtained from a study of the mine development plan, the geological conditions, seam gas content data and historical gas emission data. Account must be taken of changes in seam gas content across the reserves and geology together with the degassing effects of previous workings in a colliery where more than one seam has been worked.

3.1 PREDICTION OF FIREDAMP EMISSION RATES

Firedamp prediction models have been devised to assist not only with ventilation and gas drainage design but also operational problem solving. There are a wide variety of approaches to firedamp emission prediction and the more common of these are described in Appendix 1.

At UK collieries, the likely gas emission into a longwall district, and its dependence on coal production rate, is usually predicted using the MRDE firedamp prediction method developed by the former British Coal Corporation. This method requires the following inputs:

- Depth and thicknesses (less dirt) of all coal seams within 200 m of the roof and 70m of the floor of the worked seam
- Proposed extraction parameters (face height, face length, ash content of coal, extraction rate, length of panel)
- The gas content of the worked seams
- The positions of old workings above or below the proposed panel to be extracted

The MRDE method is unique among empirical prediction methods in that it takes account of the age of a working longwall ie. a gradual increase in specific emission over the life of a district due to the cumulative increase in the volume of coal contributing to the gas flow.

The basic model underlying the MRDE method was developed by Airey (1971) in a mathematical theory of gas emission in coalmining operations. The theory envisages the seam ahead of the coalface, and seams in the roof and floor as disturbed to varying degrees by the stresses associated with the moving coalface. The emission from the worked seam was calculated as the summation of the emission characteristics of a distribution of coal lump sizes created by the mining disturbance. Airey described the gas emission from adjacent seams in terms of the ratio of principal stresses. Thus, he was able to compute a distribution of emission parameters (time constants) around the face and hence calculate the degree of emission from seams in adjacent strata, as a function of distance from the face line.

The MRDE prediction method (Dunmore 1981) calculates the magnitude of gas flow into a particular longwall mining district as a function of the gas contents, number and thickness of seams in the disturbed zone, the proximity of the seams to the worked seam, the age of the district and the rate of advance or retreat. A computer program (FPPROG) was written to implement the MRDE prediction method in a form useful to colliery ventilation engineers. The computer program includes an algorithm which takes account of gas removed by previous under or overworking of a longwall. FPPROG was the standard programme for all British Coal collieries and is still used widely. Predicted gas flows from coal seam sources are generally within 20% of measured flows.

A simplified form of the MRDE prediction method has been published (Creedy and Kershaw, 1988) which can be adapted for computer spreadsheet application.

3.1.1 Airway Methane Concentration Peaks

When using a prediction method to calculate the air quantity required in a roadway to dilute the methane concentration to acceptable levels, it is usual to take into account maximum (peak) levels rather than mean levels of emission. Analysis of methane concentrations in the return airways of longwall faces has shown that peak levels are approximately 1.5 times higher than the mean methane concentration in the airway. For peak methane concentrations to be diluted to C per cent the following relationship must hold:

$$\frac{1.5\mathrm{F}}{1000\,Q} = \frac{C}{100}$$

Where F is the pure methane flow rate (l/s) and Q the district air quantity (m^3/s).

The above can be arranged in the general form:

$$Q = \mathrm{bF}$$

Where b is a constant corresponding to the statutory limits of *C*. For example, b has values of 0.12 and 0.075 for I = 1.25 per cent and *C* = 2 per cent respectively.

3.2 FIREDAMP DRAINAGE SYSTEMS

A firedamp drainage system needs to be able to accommodate the maximum expected captured gas mixture (methane and air) flows from all sources in the mine including working faces, salvage districts and abandoned areas.

The capability of the system to transmit the gas depends on:

- The volume of gas produced
- Flow capacity of the pipeline system
- Effectiveness of dewatering systems
- The suction generated by the exhauster pump or pumps

The volume of pure gas produced is estimated using a firedamp prediction method. Assumptions as to dilution with leakage air are then made to obtain total expected mixture flows. Manual or computer based methods are used for pipeflow calculations. The design of the drainage system should consider the potential reduction in flow due to water accumulation. The effectiveness of dewatering depends on the design allowing for the incorporation of water traps at appropriate locations, installation of the devices, and their maintenance and operation.

The highest mixture flows likely to be encountered are whilst working faces in virgin conditions. Where coal production can be limited by gas emission, the aim of firedamp drainage is to maximise pure methane flow from the district at all times. The drainage system should therefore be designed to accommodate a gas mixture of the worst case purity likely to be consistently encountered. The estimated worst case mixture flow should be within the planned capacity of the firedamp drainage system when all the extraction pumps are operating.

Methane exhausters are generally installed on the surface although underground installations which vent the collected gas into return airways, are used in some mines where drained quantities of firedamp are relatively low. Water seal extractors are used in UK mines. These are of relatively simple, robust construction, suitable for continuous operation and of proven reliability. However, they are relatively inefficient as pumps and are costly to replace. Exhausters are usually arranged in parallel.

The demand for methane pumping capacity varies with the resistance of the drainage network which depends on the capacity of the underground pipework (which is fixed) and the variable number and quality of boreholes connected to the system (a variable).

Firedamp drainage boreholes draw firedamp from the strata together with ventilation air through vertical breaks in the goaf and the roof of the roadway behind the face. Each borehole, therefore, provides a parallel flow path, the system resistance reducing with increasing numbers of boreholes connected. As the system resistance reduces, mixture flow increases in accordance with the pump curves. Whether the pure methane flow also increases depends on the quality of the boreholes. Isolating or regulating a borehole increases the system resistance. As a result, suction pressure increases, mixture flow decreases, but purity and hence pure flow, may increase as more suction is applied to the remaining more productive boreholes.

Manufacturers' pump curves indicate volume flow at the operating pressure under conditions of standard temperature and pressure. A fall in pump performance is expected due to age and wear. Accurate measurements should be made of suction, delivery pressure and flow with various pump combinations

The duty of the firedamp extraction system will vary considerably over time depending on the number of old districts, barometric conditions, coal production rates, number of operational faces and the degassing effects of previous mining. Firedamp drainage capacity cannot necessarily be increased by adding a methane pump to the surface plant. However, sufficient spare capacity in the system should be available to allow pumps to be taken out of service for maintenance or repair without detriment to firedamp drainage.

Methane concentrations (purities) in drained gas can range from a few per cent to in excess of 90% in exceptional circumstances. Some control on purity is achievable. Increasing suction in an effort to increase gas flow will introduce more air and hence reduce the gas purity. Conversely, reducing suction (eg. by stopping a methane pump) will reduce the total mixture flow but improve gas purity. The balance between gas flow and purity is achieved either by manual adjustment or by an automatic control system at the methane drainage plant. Gas purity is controlled by adjusting a by-pass valve, switching pumps off or on, and by regulating flows from sealed off waste areas underground.

4. METHODS OF FIREDAMP DRAINAGE

Gas drainage is an essential part of mining of coal seams where the gas emissions from the seams disturbed by mining are higher than can be practicably diluted by ventilation air. The advantages and disadvantages of the methods in most common use in high-production longwall coal mines (Creedy et al, 1997) are summarised in Appendix 2.

The methods used for capturing coal seam gas in coal mine workings are conventionally classified as either pre-drainage methods or post-drainage methods depending on whether gas is drained from unmined coal before mining or from the coal disturbed by longwall extraction.

4.1 PRE-DRAINAGE

Where gas pressures are relatively high and the seams exhibit reasonable permeability, horizontal boreholes drilled in the worked seam from underground roadways or shafts can be effective in reducing the gas contents of coal seams in advance of mining. This approach is not appropriate for controlling longwall gas hazards in currently operating UK mines and, with a few exceptions, attempts to apply it in the UK have not been successful.

Pre-drainage of roadway driveages, and adjoining coal panels, was practised in the former Point of Ayr colliery where unusually high gas emissions were experienced in virgin coal areas. Elsewhere, short, vertical boreholes have been drilled in the roofs of headings to control emissions of firedamp from discrete fractures in gas bearing sandstones. Where there is a frictional ignition risk in mechanised driveages, due to the simultaneous presence of flammable gas and incendive rock, low angle boreholes have sometimes been drilled in the roof to terminate ahead of the face to release the gas in advance of mining.

4.1.1 Pre-Drainage from Surface Boreholes

Coal seams in some countries are sufficiently permeable, due to a relatively open cleat structure, to allow gas and water to be produced from surface boreholes at significant rates. The coal seam usually has to be treated or stimulated in the vicinity of the well-bore to maximise the recovered flow. The most successful system of stimulation has been hydraulic fracture stimulation, "hydrofraccing" which involves creating a vertical hydraulic fracture and propagating it into the coal seam over distances up to 300 m on either side of the borehole. The pressurising medium is water, foam, gas or gel. Sand, or some other material (called proppant), is used to keep the fractures open. The fracture forms a path of high conductivity along which gas can flow into the borehole. When a number of seams are present, multiple fractures may be created in a whole series of seams from the same borehole.

The depth of most underground workings, low seam permeability, high drilling costs and surface environmental and access constraints precludes the application of this technology to deep mines in the UK.

4.2 POST-DRAINAGE

All methods for intercepting firedamp released by mining disturbance before it can enter a mine airway involve obtaining access, by some means or other, to the destressed zone above, and also sometimes below, the worked seam.

Access is gained by drilling from the underground roadways, drilling from the surface, driving roadways into the destressed zone or exploiting old workings which lie within the disturbed zone. Irrespective of the method of access, the aim is to consistently capture sufficient gas to ensure that the mine ventilation can satisfactorily dilute any remaining emissions at the planned rate of coal production. The choice of method is determined by practicality, safety and cost.

4.2.1 Pre-Drilled Cross-Measure Boreholes

In some countries, boreholes drilled into virgin ground before a retreating coalface passes are claimed to perform satisfactorily. Borehole standpipes extended with perforated steel sections have been used to improve the integrity of such boreholes. Pre-drilled boreholes from workings in one coal seam in the United States captured about 71 per cent of the firedamp produced by longwall mining (Garcia and Cervik, 1985). The reasons for the varied success of cross-measure boreholes drilled ahead of retreat longwalls are not fully understood. Mining and natural stresses, the geotechnical characteristics of the roof strata and the depth of cover are all likely to be relevant factors.

4.2.2 Drainage To The Surface Using Vertical Goaf Wells

This approach, used in Australia, China, South Africa and the United States, involves drilling vertical boreholes from the surface above longwall panels to capture gas from coal seams in the roof strata disturbed by coal extraction.

The method is applicable to relatively shallow longwall coal mines where there are few restrictions on surface drilling and the construction of surface venting sites. Due to surface environmental and depth constraints the method is not generally suitable for application in the UK.

4.2.3 Goaf Drainage From Underlying Or Overlying Roadways

In the late 1940s a method of gas drainage sometimes termed the *"superjacent heading"* or *"Hirschbach"* method was developed in the Saar coalfield in Germany which involved driving a heading above the worked seam prior to its extraction by a longwall method. Where practicable the roadway was driven in coal to reduce the cost. Sometimes boreholes were drilled from the roadway to extend its zone of influence. The roadway was then stopped-off, a methane drainage pipe being installed in the stopping to draw the gas away. Typically, a drainage roadway would be situated from 20 m to 25 m above the worked seam or less than 20 m below. The method is only practicable in the UK where advantage can be taken of existing roadways above or below the worked seam.

4.2.4 Goaf Drainage Using Long, Horizontal Boreholes Above Or Below The Worked Seam

Modern guided longhole drilling techniques have the potential to achieve a similar result to the above method without incurring the additional cost of driving an access drift and a gas drainage roadway. A borehole started from the worked seam can be guided through an arc to run parallel to the workings at a selected horizon above or below. To achieve a reasonable gas capture, and also to make due allowance for borehole damage as the longwall face retreats, three or more boreholes are required. An attempt to demonstrate the method in the United Kingdom failed due to drilling difficulties (Bennett, 1994) resulting from swelling of mudstones and borehole instability. Successful applications have been demonstrated in Australia, China and the USA. However, the method does not seem to have been widely adopted by coal mining companies.

More work is required on borehole stabilisation techniques to enable difficulties of drilling in soft material and disturbed ground to be overcome. Water management can also be a problem. Modern downhole tools are costly items and in difficult drilling situations could be lost.

4.2.5 Goaf Drainage From The Worked Horizon

Direct drainage of gas from the goaf can be achieved from pipes laid in the return roadway of a retreat face and left open at the face start line, from pipes inserted through stoppings erected at the return end of the face or in crosscuts driven from a parallel roadway. These methods are not usually efficient, high drainage capacities are required and the captured gas can be of too low a purity for utilisation. The method may be adequate where gas emissions are relatively low. However, where thick seams are mined in China, high flows and purities are obtained using this method.

5. FIREDAMP DRAINAGE IN THE UK

5.1 CURRENT STATUS OF PRODUCING UK COLLIERIES

Of the 16 producing deep mines, 13 collieries (15 longwall faces) have installed firedamp drainage systems. Three collieries exhaust methane underground and 10 are draining to the surface. Gas is used in boilers at three mines and for power generation at two other mines. The possibility of extending utilisation to a further five schemes is under consideration (Table 1).

Typical annual coal production rates per face vary from 0.5 to 0.8 Mtpa. The gas contents of the seams being worked range from some 0.01 to 15 m^3/t. The highest specific emission is around 75 m^3/t but this value arises at a mine with unusual gas capture conditions.

Table 1
Firedamp drainage in UK mines

Mine	Operator	Approx. coal output Mtpa	Seam gas content m^3/t	Firedamp drainage installed (Y/N)	Methane drainage plant	Mine gas utilisation
Clipstone	RJB	0.5	3.1	Y	Surface	-
Daw Mill	RJB	1.9	2.0	N	-	-
Ellington	RJB	0.9	0.01	N	-	-
Harworth	RJB	2.0	6.8	Y	Surface	$14MW_e$
Hatfield	Hatfield Coal	0.5	-	Y	Underground	-
Kellingley	RJB	1.7	5.2	Y	Surface	Boilers
Longannet	Scottish Coal	1.9	-	N	-	-
Maltby	RJB	1.4	6.2	Y	Surface	-
Prince of Wales	RJB	1.8	4.1	Y	Underground	-
Riccall/ Whitemoor	RJB	1.7	4.1	Y	Surface	Boilers
Rossington	RJB	1.0	5.3	Y	Surface	-
Stillingfleet/North Selby	RJB	3.5	4.8	Y	Surface	-
Tower	Tower Colliery Co.	0.6	15	Y	Surface	$6.5MW_e$
Thoresby	RJB	1.8	5.8	Y	Surface	-
Welbeck	RJB	1.6	3.2	Y	Surface	Boilers
Wistow	RJB	2.1		Y	Underground	-

5.2 SITE OBSERVATIONS

The current status of firedamp drainage practice was assessed after discussions with colliery staff and on the basis of underground observations. Visits were made to Kellingley, Maltby, Thoresby, Tower and Welbeck collieries during the period of the study. All the coalfaces visited were being worked with a longwall retreat method. Face lengths ranged from 250m to 300m.

Effort was principally concentrated on obtaining an understanding of the firedamp drainage management structure and operational procedures, and identifying good practice elements for incorporation in the guidance document shown in Annex 1.

Valuable information was also gained from the case studies which are presented in Appendix 3.

5.2.1 Drainage Borehole Configurations

Roof boreholes, depending on the specific target horizons, were typically 30m to 50m in length at angles of 60 to 65 degrees. Standpipe lengths from 13.5m to 15m were being used at different sites. Roof holes were spaced at 4m to 12m depending on the site and floor holes from 30m to 200m.

5.2.2 Coalfaces With Pre-Drilled Roof Holes

Of the five mines studied, firedamp drainage boreholes were drilled in front of the face at three. Hazardous roadway conditions behind the face and failure of rib edges were the primary reasons for moving drilling operations ahead of the face.

Captures from 20% to 45% occasionally attaining 50% were obtained but with poor consistency. Flows of 200 l/s to 300 l/s (pure) were typically recorded in the district drainage system.

At these three mines the roof holes were drilled variously at distances of 5m to 40m in advance of the face. No gas was captured ahead of the face and holes were not connected to the collection ranges until the face had passed. At one site, significant flows were not detected until holes were about 15m behind the face. Due to difficult access, few borehole flow measurements are taken. Reported individual borehole flows were 30 l/s to 40 l/s at one site and as high as 120l/s at another (pure gas basis). However, these flows soon decayed.

Purity control is achieved using a “leapfrog” system which involves connecting batches of holes to each of two district collection ranges in turn. Lack of access behind the face prevented any regulation of holes or ranges at two of the sites.

A consequence of instability behind the faces, especially where rib movement occurred was that the ranges were susceptible to damage. Evidence was seen of ranges pinched between the rib side and deformed packs. Failure of a range occasionally resulted in total loss of drainage. Without access, remedial work was not always practicable and restoration of drainage depended on the drilling and connection of new holes after blanking off the range.

The need to drill ahead of the face and the subsequent difficulties in achieving effective drainage due to lack of access behind the face stem from a fundamental problem of strata control. Whether a geotechnical solution is available has yet to be determined. More research is required into this aspect.

5.2.3 Drilling Equipment

Mini-hydrak drilling machines are in general use. Users appear to be generally satisfied with the equipment and considered it robust and reliable.

Polycrystalline diamond (PCD) drill bits are also widely used. Most PCD bits have a hard wearing cast matrix body with tungsten carbide gauge protection, well anchored cutting inserts and good flushing and cuttings clearance. Good penetration rates are possible in both coal and rock with the these bits.

5.3 CURRENT UK EXPERIENCE

A distillation of observations, previous experience and results reported in the literature indicates that:

- On retreat coalfaces, boreholes drilled over the goaf are, on average, more successful than boreholes drilled in advance
- Boreholes drilled normal to the gate road produce gas for longer periods of time than those angled towards the coalface which tend to become prematurely truncated as a result of differential strains in the disturbed roof strata
- Gas from uncut roof coal or from seams up to 10 m to 15 m above the worked seam is difficult to capture by firedamp drainage and any that is, will usually be of low quality due to difficulties in achieving air tight seals due to breaks in the roof
- Failure to consistently drill and complete boreholes near to the coalface may result in a poor and variable firedamp capture performance
- A specifically designed face-end support system is an essential element of an effective firedamp drainage system
- Inadequate strata control can lead to fracture of the range and loss of drainage due to ground and pack movement
- Firedamp drainage performance is improved through good installation, maintenance, regular monitoring and systematic drilling
- Practical gas drainage problems in collieries can generally be resolved by application of existing knowledge and techniques

From the information analysed, the principal technical factors in ensuring safe and effective firedamp drainage would appear to be:

- An engineered support system at the face-end to ensure borehole longevity
- Safe drilling location (stable ground, statutorily acceptable gas concentrations, cool air)
- Good standpipe sealing
- Standpipes and boreholes of correctly designed and installed length and geometry
- Optimum borehole spacing
- Safe access to major gas producing boreholes behind the face
- Daily flow and purity monitoring on all accessible boreholes
- Multiple ranges (2 or 3) to assist purity and suction control on batches of boreholes
- Regular monitoring of outbye district ranges for flow and purity (or remote monitoring relayed to Control Room)

5.4 GOOD FIREDAMP DRAINAGE PRACTICE

During the research some defects in drainage operations were observed and lessons were also learned from good practices already in place. It is suggested that the following should be considered when designing and operating a firedamp drainage system to accord with good practice:

- Adequate standpipe lengths are likely to be 15m or greater to ensure contact with reasonable purity gas with low air contamination
- There should be at least 5kPa of suction available inbye
- Firedamp drainage details should be included with ventilation requirements on mine plans
- Prefabricated curtains in back-return airways should extend as far back as practicable to ensure the gas “fringe” is kept well back in the waste

- No stoppings should be constructed behind the face as high concentrations of firedamp can accumulate behind them, and may migrate onto the face as a result of ventilation or barometric pressure fluctuations
- Firedamp drilling behind the face should, wherever practicable, be undertaken on the waste side to ensure ventilation with relatively fresh and cool face air
- When circumstances require drilling on the rib side, in addition to continuous monitoring of firedamp concentrations at the drilling machine, regular tests should be made for methane layering
- Standpipes are customarily sealed by allowing drill cuttings to build-up behind a densotape collar. Where consistently low gas purities can be attributed to poor standpipe sealing, alternative sealing methods or the possible need to extend the standpipe length should be examined
- All orifice plates should be clearly marked showing orientation and orifice diameter
- GRP ranges are relatively brittle and are not generally suitable for use in coal production districts. However, ease of handling and installation, compared with steel pipe, makes them the preferred material for the main ranges. However, where space is restricted and there is a risk of damage from FSV's, steel pipe should be used
- Firedamp drainage valves and regulators should be regularly inspected and maintained. Valves should be clearly marked with a number corresponding to a reference on a drainage drainage plan
- Ranges should be graded to allow water drainage. Water traps should be installed at low points. Manual drains should be checked regularly
- Procedures for the control of gas emissions from old districts should include for actions based on a 5-day barometric pressure forecast (upgraded daily)
- Refresher courses (annual) should be provided to relevant staff on gas and ventilation measurement techniques. Staff with responsibilities for firedamp drainage system design should be familiar with the available firedamp prediction techniques and pipeflow calculation methods
- Ventilation, gas and firedamp drainage data should be presented on a pro forma which clearly shows the current gas control performance and highlights any potential problems which require attention

5.5 FIREDAMP DRAINAGE MANAGEMENT

Colliery management has a duty to manage the hazardous gases released by mining, using best practicable means, to ensure safe working conditions are maintained.

Firedamp drainage is part of the mine ventilation system; gas drainage and ventilation factors therefore need to be considered together and firedamp drainage details included on ventilation plans.

A close relationship is evident between strata behaviour and gas emission potential. The choice and design of gas drainage methods must therefore be closely co-ordinated with the specification of strata control systems to ensure compatibility.

Important factors, additional to technology, which are essential to safe operations are:

- An understanding of the basic principles of gas control by the colliery management and supervisory staff
- Provision of suitable technical training
- A motivated, involved workforce
- A structured approach to design and implementation of measures
- Setting and maintenance of sound, basic operational standards

- Good supervision and
- Technical support from specialists as required

Breakdown of drilling machines, ventilation or gas extraction plant can lead to hazardous conditions developing underground and lost coal production. The management system should therefore require all firedamp drainage related equipment to be included in the planned, preventative maintenance scheme for the mine.

Continuous remote monitoring, which continues to function in conditions of high methane, provides the mine environmental engineer with a powerful tool and a more complete record of the environment than statutory measurements alone.

Computerised environmental monitoring systems provide large amounts of data but the information is not always exploited to maximum advantage. Greater use could be made of remote monitoring systems at collieries for analysing methane problems. Continuously monitored methane concentrations measured in return airways of coal production districts combined with airflow data, to yield pure methane flow, can be correlated with coal production data to provide specific emission values and assist in the identification of unusual gas emission events which may require further investigation.

Safety legislation specifies precautions to be adopted in the design, selection of equipment and operation of firedamp drainage and utilisation plant at collieries. Typical requirements are for monitoring of methane concentration in and around the plant, provision of flame traps and automatic shut down systems if methane concentrations fall below a minimum safe concentration, typically 30 per cent.

6. RECENT RESEARCH

6.1 FIREDAMP FLOW PREDICTION AND MODELLING (SEE ALSO APPENDIX 1)

Research has recently been undertaken on gas flow modelling and emission prediction in various research and academic institutions in the United States, Europe, Canada, Australasia, China and South Africa. Most of the research on methane flow modelling for coal mines is aimed at improving the accuracy of simulations and enhancing the understanding of strata behaviour, gas flow and gas emission processes. Future methane prediction models are likely to be more general and less empirical than existing models but of a complexity which may make them unsuitable for day to day colliery ventilation planning purposes.

Whilst much of the research on gas emission modelling is primarily of academic interest, the understanding of mining and strata processes which is gained has practical benefits for the design of firedamp drainage systems. Studies to integrate gas reservoir and strata behaviour models could contribute to an appreciation of the factors pertinent to improved placement of cross-measures boreholes.

Considerable research on methane measurement and emission prediction has been undertaken in Europe (Belgium, France, Germany, Spain and the United Kingdom) principally by state agencies with financial support from the European Coal and Steel Commission (ECSC). Most of the development work on methane emission prediction for coal mining was completed during the 1970's and 1980's.

The School of Chemical, Environmental and Mining Engineering, the University of Nottingham (Dr J S Edwards and Dr T X Ren) have developed a longwall methane flow model incorporating Computational Fluid Dynamics (CFD) techniques to assist in representing stress-permeability relationships in the goaf and surrounding strata. The stress-permeability behaviour of Coal Measure rocks has been studied along with the influence of mining induced stress on post-failure rock mass permeability. Gas drainage models and a firedamp drainage network model have also been developed. Currently, a surface goaf borehole model is being developed for application in mines in China.

The Earth Resources Engineering Department of Imperial College in London (Professor S Durucan) is involved with gas flow modelling and research into the stress sensitivity of the permeability of coal matrix and fracture systems. A non-linear finite element model is being used to study the dynamic changes in the state of stresses and the post-failure behaviour of coal seams and surrounding strata during longwall mining. Failure zones are defined at each extraction time step and used in characterising the mining induced stress-dependent permeabilities of the coal seams and surrounding strata.

The University of Leeds has undertaken research on firedamp drainage systems. Recursive statistical techniques have been applied to continuously monitored gas flow and purity data. Real time data processing techniques were then developed which could be used to control methane drainage plant.

The Institute of Occupational Medicine (IOM) in the UK (Dr A D Jones) in conjunction with the Institute de l'Environnement Industriel et des Risques (INERIS) in France (Mr C Tauziede) and Charbonnage de France have constructed aerodynamic scale models for predicting methane concentrations around retreat longwall coalfaces complemented by CFD simulations and underground studies in operational coal mines. These studies form the basis for further developments including consideration of firedamp drainage.

6.2 IMPROVING METHANE DRAINAGE OPERATIONS

Most of the practical research on firedamp drainage was undertaken by the former British Coal with involvement from University mining departments in some instances.

Following privatisation of the coal industry ongoing projects were completed by consultants.

6.2.1 Improved Drainage Of Methane Gas

This project, funded by British Coal, the ECSC and the DTI investigated means for improving methane drainage operations in mines (IMC Geophysics Ltd, Dec 1997). The research concentrated on the application of horizontal drilling techniques.

A trial was planned to install a horizontal borehole 36m above the Deep Soft workings at Harworth colliery (DS14's). The plan involved drilling three separate steered boreholes. They would be started 350m back from the face and then at two further 700m increments. The proposed drilling horizon was a 5m competent sandstone bed. Two unsuccessful attempts were made to install a standpipe across the relatively soft measures into the sandstone before the trial was abandoned.

A 525m angled (45^o)goaf borehole was planned at Silverdale colliery for installation above the worked Ragman seam together with boreholes in the underlying Hams seam. The goaf borehole was abandoned at 314m due to drilling difficulties. The sub adjacent drilling was abandoned after encountering unexpected geological conditions and problems with stabilising the hole.

Point of Ayr colliery provided the final test site. Drilling was planned with the aim of proving strata beyond a fault and then installing a long borehole to de-gas a block of coal in advance of mining. Drilling and geological difficulties prematurely terminated the exercise.

No gas drainage was achieved during the project and it was concluded that *present technology for drilling steered and near-horizontal wells from within UK mines is generally not capable of producing reliable and repeatable progress*.

6.2.2 Methane From Rapidly Advancing Drivages

This study, undertaken as part of the DTI Coal R&D programme, included topics of relevance to firedamp drainage (IMCL Ltd, Dec 1997). Firedamp flow data were analysed statistically. The methane flows in the drainage range were found to be skewed with the peak value close to the mean. It was concluded that a simple average of random drainage samples could over-estimate the mean.

Computer modelling using 2-d and 3-d CFD techniques was undertaken to study nitrogen inertisation of longwall goafs and gas concentrations in back-return systems. The possibility of extending the 3-d approach to model firedamp drainage was discussed.

6.2.3 Monitoring Of Gas Flows In Firedamp Drainage Boreholes

The University of Nottingham developed a device which could be inserted in boreholes to measure flow, purity and suction at different locations (Riley and Edwards, 1991). Although the research was completed some ten years ago, the technique is considered worthy of consideration for application to drainage borehole performance monitoring and design.

7. TECHNOLOGY NEEDS

7.1 PLANNING TOOLS

Firedamp drainage systems are designed on the basis of expected gas emissions. Those responsible for designing and specifying the drainage requirements for a new face therefore need ready access to a reliable, easy to use gas emission prediction method. The MRDE emission prediction method is well proven, but FPPROG the computer program used to implement the method is dated and not freely available. There is a need, therefore, for a user-friendly, modern emission prediction program that can be made available to all mines and which they can adapt to suit their particular planning procedures.

7.2 STRATA CONTROL

There appears to be a strong correlation between strata control at the return-end of the face, including the back-return, and firedamp drainage borehole performance. Strata control techniques require further research and development to establish a technology which will enable roadway support and firedamp drainage needs to be optimised.

7.3 BOREHOLE MONITORING

Borehole performance data are an essential ingredient of an effective firedamp management system. However, boreholes behind the face are not always accessible. A cost-effective technology is required to enable borehole information to be gathered remotely.

7.4 GAS EXTRACTION EQUIPMENT

The methane extraction pumps used at most mines are manufactured and supplied by Nash Hytor. New spares are difficult to obtain for older types of pump and new pumps are costly. Second-hand pumps are available but their performances may not match those of new pumps. The water seal used in these devices introduces complexities of operation, pump efficiencies are low and water carry-over creates problems for flame traps, valves and any gas utilisation on the discharge side of the plant.

Modern dry seal extractors are available which are smaller, lighter, less costly and more efficient than the pumps in current use at mines. They are used for extracting gas from abandoned mines but have not yet been approved for introduction into working mines.

8. CONCLUSIONS

UK coal mines do not have an immediate need for innovative drainage techniques but they could benefit from more effective firedamp drainage management as described in the guidance in Annex 1.

Most research on gas emissions in mines has concentrated on computer modelling of gas release and transport processes, ventilation and drainage network models and prediction of emission rates. Little applied research on firedamp drainage has been done in recent years. While a number of aspects would benefit from further research, the most important is the study of the relationship between drainage borehole stability and face-end support systems.

Firedamp drainage capture on retreat coalfaces could be improved if the relationship between strata mechanics and drainage borehole performance was better understood.

9. RECOMMENDATIONS

Four areas can be highlighted in which further R&D is needed:

- Furthering the understanding of the link between face-end strata control and drainage borehole performance
- Development of an accessible, easy to use PC program for predicting firedamp emissions and ventilation requirements
- Remote monitoring of drainage boreholes
- Improving the efficiency of firedamp drainage extraction

Of the above, the first topic is considered the highest priority.

9.1 GEOTECHNICAL ASPECTS OF FIREDAMP DRAINAGE

There appears to be a strong link between strata control and effective firedamp drainage. Preliminary studies by Wardell Armstrong and Graham Dawes Associates have shown that borehole stability can be improved by installing a pack system designed on the basis of strata measurements and observations. More work is urgently required in this area to establish the support design criteria to optimise drainage performance. Any solution will be site specific but it should be possible to determine general principles that are applicable to all situations.

A suggested programme of work would involve:

- Identification of 2 underground test sites (retreat longwall panels)
- Characterisation of the existing support system
- Installation of strain gauges to measure deformation immediately ahead of the face and in the back-return (using extensometers, load cells and instrumented firedamp drainage standpipes
- Interpretation of the geotechnical environment
- Monitoring of borehole drainage performance and integrity (including use of the University of Nottingham flow probe described by Riley and Edwards, 1991)
- Modifying support system, if appropriate, and repeat monitoring (Tasks 3 to 5)
- Compare results from both sites
- Using data from one site, develop a FLAC model and use to test a wider range of conditions
- Validate the model using data from the second site
- Evaluate the commercially available “Roofgas” geomechanical and gas release computer model developed by Kidybinski and Lunarzewski
- Derive and describe design rules for face-end and back-return support systems.
- Preparation of a final report

9.2PREDICTION OF FIREDAMP FLOWS AND VENTILATION REQUIREMENTS

The determination of ventilation and firedamp drainage performance requirements for a new longwall depends on the availability and accuracy of firedamp emission predictions. A computer programme for predicting gas flows was produced for British Coal some fifteen years ago but it is not freely available and it cannot be easily adapted to suit the requirements of individual mines. It is, therefore, recommended that a relatively simple, modern “spreadsheet” based version is developed to suit today’s requirements. The aim would be to make gas flow prediction a user-friendly tool that was readily accessible to colliery environmental engineers, ventilation and methane drainage officers.

9.3 REMOTE MONITORING OF DRAINAGE BOREHOLES

Borehole monitoring data are essential for system management and future design. Boreholes behind a retreat face are sometimes inaccessible and they are not in an environment favourable to the installation of remote electrical monitoring equipment. Alternative approaches are therefore needed. Some use has been made of long sampling tubes, extended to the back-return, for monitoring gas purity but the method is cumbersome. A possible new approach to purity monitoring which could be evaluated is to remotely measure surface temperature of steel drainage pipework (protruding standpipe, possibly) using a hand-held laser probe. As the temperatures of ventilation air and firedamp are usually significantly different, there may be a usable correlation between gas purity and temperature.

9.4 IMPROVING THE EFFICIENCY OF SURFACE METHANE DRAINAGE PLANT

Dry seal extractors offer considerable attractions in terms of increased efficiency, ready availability and low cost compared with the conventional wet-seal extractors used by all UK firedamp drainage systems. The practical and safety aspects of using dry seal pumps should, therefore, be examined in detail. Depending on the outcome of the investigation, and the acceptance of HSE mines inspectorate, guidance could be developed to facilitate their controlled introduction at UK mines.

REFERENCES

- **Airey E M** (1971), A theory of gas emission in coalmining operations, Presented at *The 14th International Conference of Directors of Safety in Mines Research,* Donezk, USSR (1971)

- **Alarcon D, Silva F** (1990), Expert system for the evaluation and reduction of methane explosions risk in coal mines, APCOM (1990)

- **Barker-Read G R, Aghababee H, Lumsden P** (1992), A study of airway/methane drainage interaction, Leeds University Mining Association (1992)

- **Bennett S C (1994)** Improved safety and control of methane gas in UK coal mines. In: *Prospects for clean coal technology, proceedings for Nottingham coal conference.* Nottingham, UK, Department of Trade and Industry, ETSU, Harwell, Oxfordshire, 10 pp (1994)

- **CEC** (1990), Methane diagnostics programme for colliery use, Final Report on ECSC Contract 7262 - 32/230/08 (1990)

- **CEC** (1988), Investigation of firedamp and its emissions in coal seams, Final Report on ECSC Contract 7220-AC/819, Report EUR 11477 EN (1988)

- **CEC** (1989), Short-term forecasting of methane emission levels using continuously monitored data, Final Report on ECSC Contract 7220 - AC/832, EUR 12326EN (1989)

- **CEC** (1992), Prediction of gas emission on short faces and drivages, Final Report on ECSC Contract 7220-AC/834, Report EUR 14189EN (1992)

- **Creedy D P, Kershaw S** (1988), Firedamp prediction - a pocket calculator solution, In *The Mining Engineer*, pp 377-379 (February 1988)

- **Creedy D P** (1986) Methods for the evaluation of seam gas content from measurements on coal samples. *Mining Science and Technology*; **3**; 141-160 (1986)

- **Creedy, D P, Saghafi A, Lama R** (1997). Gas control in underground coal mining, IEA Coal Research, IEA CR/91 pp120, April 1997

- **Dixon D W, Longson I** (1993), A statistical method for methane prediction and improved environmental control, Proceedings of The *6th US Mine Ventilation Symposium,* Salt Lake City, UT, USA (21 - 23 June 1993)

- **Dixon D W, Ozveren C S, Sapulek A T, Tuck M A** (1995), The application of neural networks to underground methane prediction, Proceedings of *The 7th US Mine Ventilation Symposium*, pp 49-54 (1995)

- **Dunmore R** (1981), Prediction of gas emission from longwall faces, In *The Minimg Engineer*, pp 565 - 572 (February 1981)

- **Dunmore R** (1982), Predicting methane emission in real time for longwall faces, Presented at *The 1st Mine Ventilation Symposium*, University of Alabama, USA (1982)

- **Durucan S, Daltaban T S, Shi J Q, Foley L** (1993), Permeability characterisation for modelling methane flow in coal seams, paper 9315, Presented at *The 1993 International Coalbed Symposium*, Tuscaloosa, A L, USA (17 - 21 May 1993)

- **Garcia F, Cervik J** (1985) *Methane control on longwalls with cross-measure boreholes (Lower Kittanning Coalbed)*. Report of Investigation RI 8985, US Department of the Interior, Bureau of Mines, 17 pp (1985)

- **IMCL** (1997**).** Methane from rapidly advancing drivages. Report No. COAL R131, DTI Coal R&D Programme, Dec 1997

- **IMC Geophysics Ltd** (1997**).** Improved drainage of methane gas. Report No. COAL R130, DTI Coal R&D Programme, Dec 1997

- **INERIS** (1992), Applications de la connaissance du mode de dégagement du grisou pour la conduite des exploitations rapides, Project de recherche, CCE 7220 - AC/319 (1992)

- **Jensen B, Gillies A D S, Anderson J M, Jones N** (1992), Review of methane emission and prediction research in longwall coal mines, In *The Australasian Institute of Mining and Metallurgy Proceedings*, No 1, pp 11 - 17 (1992)

- **Kidybinski A, Lunarzewski** (1994), Floor gas and roof gas simulation programs, Lunagas Pty Ltd, Newcastle (1994)

- **Lunarzewski L W, Lunarzewski A L, Pilcher R C** (1995), A new approach to predict underground gassiness for design of gas capture and ventilation, Proceedings of *The 7th US Mine Ventilation Symposium*, pp 61-66 (1995)

- **Moll A T J, Lowndes I S (1994)** The computer simulation of the optional design and performance of methane drainage ranges. *Mining Engineer* (London); **154** (394); 9-16 (Jul 1994)

- **Noack K, Opahle M** (1992), Progress achieved in the prediction of gas emission. Proceedings of *The 5th International Mine Ventilation Congress*, Johannesburg, South Africa, pp 79 - 87 (1992)

- **Patton S B, Fan H, Novak T, Johnson P W, Sanford R L** (1994), Simulator for degasification, methane emission prediction and mine ventilation, In *Mining Engineering (Littleton, Colorado)*, Vol 46, part 4, pp 341 - 345 (April 1994)

- **Riley P A, Edwards J S (1991),** The measurement and comparison of methane drainage efficiencies in longwall advance and retreat workings, Mining Science and Technology, 13, pp 1-15, Elsevier, 1991

- **Saghafi A** (1989), A study into face gas emissions during heading development, Presented at *The 23rd International Conference of Safety in Mines Research Institutes*, Washington, DC, USA (11 - 15 September 1989)

- **Saghafi A, Jeger C, Tauziede C, Williams R A** (1987), A new computer simulation of in-seam gas flow and its application to gas emission prediction and gas drainage, Presented at *22nd Conference Internationale des Institutes de Recherches sur la Securite dans les mines*, Beijing, China (4 - 6 November 1987)

- **Tauziede C, Pokryszka Z** (1993), Dynamic prediction of methane emission at longwalls, Present at *The 25th International Conference on Safety in Mines Research Institutes*, Pretoria (1993)

- **Pokryszka Z, Tauziede C** (1994), Evolution des methodes de prevision du degagement grisouteux, INERIS à CdF, Hambourg-Haut (2 June 1994)

- **Wala A** et al (1989), University of Kentucky mine ventilation manager, Proceedings of *The 4th US Mine Ventilation Symposium*, USA, pp 307 - 316 (1989)

- **Williams R J, Maddocks P I, Gale W J** (1992), Longwall gas emission modelling : practical application and research requirements, Present at *The Symposium on Coalbed Methane Research and Development in Australia*, Townsville, Australia, Vol 5, pp 1-5 (1992)

- **Yansheng D** et al (1990), BURST 10: an expert system on coal and gas outburst control, unpublished paper, Presented at *China Mine Safety Chief Engineers* Symposium, Wuxi, China (1990)

APPENDIX 1

FIREDAMP PREDICTION MODELLING AND METHODS

Methane emission prediction models usually involve one or a combination of empirical, numerical, analytical or statistical techniques. Predictions may be applicable over a time basis of a few minutes or a few weeks. They may assume steady coal production or allow for variable rates of advance. Some models are designed specifically to predict emissions in longwall sections, others to predict emissions in headings. There are also a substantial number of coalbed methane simulators which have been developed to assess the gas production potential of virgin coal seams; most of the recent models are of this type. Emissions of gas which occur as a function of the rate of strata disturbance, assuming a fixed geology and mining method, can generally be satisfactorily represented by mathematical equations. Unusual emission events, such as sudden emissions of gas from the floor are often too complex to model although the causal processes may be reasonably well understood. Knowledge - based problem solving approaches (Expert Systems) have been used to make forecasts associated with these types of phenomena.

Methane prediction models can be divided into four different categories:

- Empirical prediction models
- Simulation models
- Short-term forecasting models (pseudo real-time)
- Expert systems

These tools can aid both the design and management of firedamp drainage systems.

Empirical Models

The most common method of methane prediction involves simply using specific emission values obtained from previous experience of a mine, a particular area of a mine or of neighboring mines where similar mining methods are being used in similar geological conditions. District ventilation and gas drainage planning is often adequately served by this approach. Sometimes estimates are scaled to take account of known differences in seam methane contents.

Specific emission method

For many practical mining purposes this simple method is considered satisfactory provided that factors which may lead to unusual emissions can be identified in advance. Implementation of the method is assisted by systematic recording and processing of mine environmental data.

Specific emission is used as a ventilation planning parameter in many collieries throughout the world, but not always correctly. Emission on a particular day depends not only on the rate of advance achieved on that day but also on previous days. Gas continues to flow when coal production stops. The parameter must therefore be determined from measurements made over a period of at least a few months of steady production, and preferably longer.

The observed relationship between specific emission and face advance or coal production rate derived using spot measurements exhibit scatter. Flows measured near the beginning of a production shift would be lower if the previous shift had not produced coal than if they had been taken towards the end of the current shift because of the general decrease in background due to periods of non production. When a high coal production week follows a low production week, the emission in that week will be lower than for continuous high production.

Empirical firedamp prediction methods

Gas emission prediction methods for longwall workings have been developed in most of the coal producing countries of western Europe, Poland and the former Soviet Union. The methods are usually fairly simple mathematically, requiring few input parameters and some are specific to a particular country or coalfield.

The longwall gas emission prediction methods consider some or all of the following gas emission sources:

- Coal seams in a gas emission zone above and below the worked seam
- Rock strata in the gas emission zone
- The worked seam itself
- Coal on conveyors

The zone above and below the workings from which methane is released as a result of longwall mining may extend up to about 200m above and down to about 70m below the worked seam. Coal seams are the principal gas source but some methods also make an allowance for additional gas from the rock strata. In the German methane prediction method (Noack and Opahle, 1992), nominal seam gas contents are allocated to the strata and then attenuated by multiplying by 0.019 for mudstone, 0.058 for sandy shale or 0.096 for sandstone. Up to 50% of the methane flow into some UK mines is probably derived from gas-filled sandstone reservoirs which have been disturbed by longwall mining.

The European methods are similar to each other in principle. The zone of gas emission around the workings is usually represented by a simple geometric form. A concept known as the "degree of emission" is used to represent the proportion of gas released from a specific stratigraphic horizon. It is usually expressed as a percentage of the virgin gas content. The degree of gas emission is estimated for each stratum and the rate of gas flow obtained by multiplying the expected emission per tonne of coal by the proposed coal extraction rate. The British Coal method developed at the former Mining Research and Development Establishment (MRDE) is unique among the European methods in that it includes the dimension of time. The degree of emission is assumed to depend on the distance of a gas source from the worked seam and the age of the longwall working. The method originally took account of increased stresses with increase in the depth of working but later studies were unable to prove any depth dependence of gas emission rates.

The limits of the emission zone in the French method are of the order of 170m in the roof and 60m in the floor of the mined seam. Within this zone, the desorbable gas content of a seam decreases from its initial gas content to a final residual gas content depending on its distance from the mined seam. The amount of gas released from rock strata is calculated according to the porosity of the rocks, the initial in situ pressure and the residual pressure (INERIS, 1992). Application of the method is preceded by calibration on a reference face. Due to its substantial empirical content, the method is not readily transportable elsewhere.

Noack and Opahle (1992) have described progress with gas emission prediction methods in Germany. Two methods for prediction of the proportion of gas content emitted from the seams disturbed by mining are mentioned:

- Degree of gas emission methods which assumes that gas release depends on geometric location of the source relative to the coalface and is independent of the initial gas content
- The gas pressure method which considers initial gas pressures and spatial factors

The degree of emission method uses empirical exponential equations for calculating emissions from the roof and floor. The practical limits are assumed to be 165m in the roof and 59m in the floor. The gas pressure method involves dividing the disturbed roof area into three zones; "caved", "cleaved" and "weakened" and the floor into two zones; "loosened" and "weakened". Each zone is characterised by a specific residual pressure gradient. There are no arbitrary limits to the gas release zone, and the effect of coal extraction height is accounted for.

The German methods determine the mean gas emission assuming a steady advance. The predictions are only applicable once the coalface has advanced sufficiently for the emission zone to have fully developed. Additionally, the face has to be longer than 180m to 190m at 600m working depth and longer than 220m to 240m at 1000m depth. The equations on which the methods depend rely on empirical relationships that are site specific and not necessarily applicable elsewhere without "tuning".

The basic model underlying the MRDE method was developed by Airey (1971) in a mathematical theory of gas emission in coalmining operations. The theory envisages the seam ahead of the coalface, and seams in the roof and floor as disturbed to varying degrees by the stresses associated with the approaching coalface. The emission from the worked seam was calculated as the summation of the emission characteristics of a distribution of coal lump sizes created by the mining disturbance. Airey described the emission from adjacent seams in terms of an emission parameter which depended on the ratio of principal stresses σ_1/σ_3. Thus, he was able to compute a distribution of emission parameters (time constants) around the face and hence the degree of gas emission from seams in adjacent strata, as a function of distance from the face line.

The MRDE prediction method calculates the magnitude of the gas flow into a particular longwall mining district as a function of the gas contents, number and thickness of seams in the disturbed zone, the proximity of the seams to the worked seam, the age of the section and rate of advance or retreat.

A computer program (FPPROG) was written to implement the MRDE prediction method in a form useful to ventilation engineers.

Predicted and measured gas flows have generally been in good agreement, with accuracies better than 20% in most instances. FPPROG is not currently available to mines as a commercial software package. However, a simplified method has been published (Creedy and Kershaw, 1988) which could be adapted for spreadsheet application and made available to all collieries.

British Coal research into gas emissions when working single virgin coal seams revealed that where longwall faces are less than about 250m in length, the de-stressed zone in the roof may not extend as high as 200m (CEC, 1992). It was found that progressively shorter faces tend to produce correspondingly smaller heights of emission zone in the roof leading to decreasing emissions per tonne of coal mined due to the smaller number of seams disturbed. The emission zone usually develops to its full height of up to 200m, irrespective of face length, in a sequence which has previously been disturbed by mining.

Current methane emission prediction models for longwall coal mines have been reviewed by Jensen et al (1992) in Australia. European and US models were criticised for their lack of sophistication and use of too few variables to represents the complexities of the mining situation. They listed 36 variables which affect methane emission rate. The writers were probably correct in their scientific analysis but totally misunderstood the practical requirements of the user. They suggested that a "universal" gas emission prediction method ought to be developed. Whilst this would be academically satisfying it is doubtful whether the coal mining industry would recognise such a priority. It is only necessary that a prediction method works satisfactorily within the realm of a particular mining company.

Williams et al (1992) considered the ideal model based on physical principles of rock and fluid mechanics which included stress, permeability, fluid and rock property conditions *"unlikely to be worth the effort"* from a commercial point of view.

A current view is that the flow of gas into longwall workings is probably determined not by the extent of coal fracturing but by the extent of the fracture zone in the surrounding rock mass which allows the gas to flow across the measures. This occurs because coal is inherently weaker than the surrounding strata and will therefore break before any migration paths are available. Confirmation of the hypothesis would facilitate an approach to gas flow modelling for longwall faces which involved calculating the extent of rock failure resulting from coal extraction. The model would then not be limited by such factors as face length and depth as they would be intrinsic to the calculation.

Commercial PC based computer programs "Floorgas" and "Roofgas" described by Lunarzewski et al (1995) use empirical rock failure criteria to process geomechanical and geological input data and predict gas emission for selecting mining configurations. Where the appropriate input data are available, gassiness predictions of 10% to 15% accuracy are claimed for Australian conditions. The model is primarily designed to identify the potential gas release regions around the workings by assessing the stress distribution patterns and does not provide a specific methane emission rate. However, the link this approach offers between drainage performance and strata mechanics would merit further investigation.

Empirical prediction of emissions from the worked seam and headings

Longwall prediction methods include an allowance for gas emission from the worked seam. As this component may represent only 10% to 15% of the total gas make in many longwall mines, a high precision is not essential. The principal gas contributors in this situation are the coalface itself, the cut coal at the machine and coal on the face conveyors.

In a coal heading, some gas will also be emitted from the exposed sides of the roadway but as the flow rates are small there has been little interest in developing prediction models. Unusually high flows may be encountered where headings enter mining or geologically disturbed zones but these situations are not easily modelled. Exceptionally high gas flows were experienced in virgin driveages in the former Point of Ayr colliery, North Wales, but similar conditions are not found in any collieries currently being worked.

To obtain a measure of typical gas flow rates, two virgin headings in the Selby coalfield were closely monitored (CEC, 1992) but it was not possible to trace the decaying emission along the driveage. The degree of emission was some 60% of the initial gas content with 30% to 50% of the total emission occurring in or near the cutting zone.

Pokryszka and Tauziede (1994) described work in French collieries to develop a prediction method for headings using Airey's empirical emission equation which involving summation of terms representing daily elemental advances.

Empirical methane emission equations have been developed in Germany (Noack and Opahle, 1992) to describe emissions from longwalls (including a correction for the face end configuration), sidewalls of headings, heading faces, conveyed coal and from seams intersected by cross-measures drifts.

Simulation Models

Methane flow simulators have been developed for both coal mining applications and for projecting coalbed methane production from unmined coal seams. However, these gas flow simulators are generally only applicable to the worked seam and hence there use is limited to the design and analysis of pre-drainage systems.

The closer the simulation approaches reality, the greater the degree of complexity. One advanced research model (Durucan et al 1993) considers dual-porosity, (representing coal matrix and microfracture), dual permeability (gas and water flow) and stress dependence of macropore permeability. Saghafi (1989) and Saghafi et al (1987) developed a non-equilibrium desorption model specifically for coal mine emissions. The model solves two-dimensional problems using a finite difference method. Account is taken of the effects of mechanical stresses, pore pressure, coal shrinkage and dewatering on seam permeability.

A computer model described by Patton et al (1994) uses a coalbed methane reservoir simulator for prediction of gas flow in pre-drainage boreholes and on longwall coalfaces. A ventilation network modelling facility is also incorporated.

Most of the models exist only as research codes. These are the subject of intellectual property rights and would not normally be made available to third parties. However, some commercial gas flow simulation software is available but its application to coal mines is limited by an inability to account for the removal of coal as the mine workings progress through time.

COALGAS, a commercial simulator available from by S A Holditch and Associates (SAH) Inc, has features which allow both coalbed methane and mining applications. The model divides coal seams into discrete blocks. Each grid block is assigned reservoir properties such as permeability, porosity, adsorbed gas content and water saturation, using available geologic and engineering data. Grid blocks that represent parts of the coal seam which will be removed by mining can be removed from the simulation at the appropriate times, without re-starting the simulation run. As the calculation proceeds, each movement of the roadway is simulated by removing part of the grid and the model estimates the gas flow from the roadway face. In addition, the volume of gas in the removed coal blocks is recorded. This provides an estimate of the potential gas volume that may be liberated, in addition to gas flow across the roadway face, due to the breaking of the mined coal. These simulations provide an estimate of the amount of methane that must be handled by a mine's ventilation system and also assist in the planning of a suitable pre-drainage programme. The volume of gas flowing into roadway developments can also be estimated. Arrangements can be made with SAH to receive the software on a free-trial basis.

A computer simulation technique for designing and improving the performance of methane drainage systems has been described by Moll and Lowndes (1994). These types of planning aid rely heavily on remote monitoring systems to provide representative and accurate input data. In the future, closer links are likely to be developed between centralised colliery monitoring systems and computerised planning aids.

Use of CFD for methane prediction

Computational fluid dynamics (CFD) has been used to simulate the localised effects of ventilation changes on methane concentrations and distributions around machines in headings and on longwall faces and also for studying the gas emission behaviour of goafs. Whilst providing a rapid means of evaluating technological changes the technique must be used with care and calibrated against field or full-scale test results. Users should be conversant with the physical processes they are modelling and have a sound understanding of fluid mechanics. However, CFD cannot provide technical solutions to methane emission hazards, only assist in their evaluation.

Short-Term Forecasting Models

The aim of short-term forecasting is to identify potential gas problems by predicting likely methane emissions on the basis of intended coalface advance or production rates and comparing expected and actual values. It is essentially a process control system which uses continuously monitored mine environmental data as input. The automatic provision of coal production information is also desirable but not always readily available on the same data input stream as the colliery environmental data.

Researchers at MRDE experimented with simple correlations between mean daily methane data and tonnage mined from a longwall on a particular day and the two preceding days but the results were not always satisfactory. Success was eventually achieved by weighting contributions due to previous coal production shifts by a progressively decreasing amount (CEC, 1989). An algorithm was produced to predict "normal" emissions on a shift by shift or day by day basis, unusual data being highlighted as anomalies requiring management attention. The method was tested in pseudo real time mode on a computer simulation but did not reach the colliery trial stage due to difficulties accommodating the algorithm in the mine monitoring computers.

The statistical approach to gas emission prediction on a weekly basis has also been applied to mines in the Lorraine coalfield of France (Tauziede and Pokryszka, 1993). It was found that the volume of methane released depended on the advance during that week and to a lesser extent on those during the previous two weeks. The method was found to be unsatisfactory during the early life of a face until an advance of about 200m had been attained (ie. the "square" position where the length of goaf produced equals the face length). Apart from this limitation, promising results were produced for a number of faces. However, on some faces where there were interactions with other workings or where intensive gas drainage was taking place, poor correlations were obtained.

Dunmore (1982) demonstrated how the MRDE (British Coal) steady-advance methane prediction program for longwall coalfaces might be adapted as a quasi real-time model. The idea was that predictions could be updated weekly, significant differences between actual and predicted emission quantities for the following week being indicative of possible abnormalities requiring attention. A start was also made on adapting Airey's variable advance model (CEC, 1989) for short-term prediction but the project was not completed.

Barker-Read et al (1992) investigated the application of time series analysis methods to the problem of modelling methane concentration variations in coal mines. Their interest was in examining the effect of changes in methane drainage system performance upon the purity of drained gas and also the effects of interactions between ventilation and drainage systems on methane concentrations in the airway. Conventional time series analysis was found to be inadequate for tracking both slow and rapid fluctuations. However, a recursive estimation technique, which updates parameter values in a reference multi-variate model at each time interval when new information becomes available, was found to show promise. Its possible application would be in methane drainage extraction control systems.

Dixon and Longson (1993) constructed a multi variate time series model to predict hourly airway methane concentrations on a longwall section purely from a knowledge of coal production. The model was comprised of components which notionally represented the instantaneous release of methane from coal cutting, release of methane from the coalface and conveyed coal, and subsequent release of methane from adjacent strata over longer periods of time. No account was taken of air quantity. As methane concentration is sensitive to fluctuations in airflow this omission limits the practicality of the actual models demonstrated. In a later development (Dixon et al, 1995), data on methane concentration and coal production obtained from an underground coal mine were used to train a neural network to `learn' the underlying patterns of methane emission and hence forecast methane concentrations in the underground workings.

Possible applications for short-term methane prediction models in collieries are for controlling methane quality in drainage systems which provide gas for utilisation or for providing advance warning of a methane control problem. In many instances, short-term prediction methods would not assist colliery ventilation staff with day to day problem solving any better than the graphical outputs obtained from remote colliery environmental monitoring systems. A print-out which shows methane concentration, air quantity and coal production on a common time base would facilitate diagnosis of most longwall district gas control problems.

Expert Systems

Increase in methane emissions as a result of increases in coal production or smooth changes in other variables can usually be predicted by conventional mathematical modelling. However, methane problems often arise as a result of abnormal conditions such as interruptions to ventilation, intermittent caving of the goaf, loss of bleeder roads, the effect of rapid barometric pressure falls on sealed-off areas and emissions of gas from dyke intersections. Most of these events are predictable in their occurrence but not in terms of their timing and precise effects. Knowledge and practical experience provides an indication of the likely outcome of a particular event and generally also a means of minimising its impact. The heuristic approach adopted by a human specialist can be incorporated into a computer program known as an Expert System. Expert Systems manipulate knowledge rather than data and are particularly suited for assessing processes which are too complex or ill-defined to permit mathematical analysis.

Expert systems on ventilation and methane control have been introduced into the mining industry in various countries (see Table 3).

Table 3
Methane related expert systems

System name	Country of origin	Developed by	Approximate date	Application
METHPRO	USA	USBM (Kissel et al, 1987)	1986/7	Diagnosis of methane control problems in US coal mines
UKMVM	USA	University of Kentucky (Wala et al, 1989)	1989	Ventilation management using analyses of continuously monitored underground environmental data
UFEL	UK	British Coal (CEC, 1988)	1986	Assessment and minimisation of unusual gas emission risks in UK coal mines
HELPDRAIN	UK	British Coal (CEC, 1990)	1990	Identifying and resolving methane control problems (incomplete)
BURST	China	(Yansheng D et al, 1990)	1990	Predict the risk of coal and gas outburst and advise on control methods

The writing of Expert System programs is aided by the availability of commercial "shells" within which the knowledge can be logically structured. Programs are generally written by a specialist familiar with knowledge based computer systems assisted by a technical expert who provides a detailed interpretation of available information, seeking additional input as required.

A program to assess unusual firedamp emission levels (UFEL), was developed by British Coal (CEC, 1988) to complement its methane prediction program. UFEL was designed to assist ventilation engineers predict the likelihood of unusual methane emissions occurring in a particular mine or section. The program indicates measures for reducing the potential risks. By combining geological, mining and ventilation knowledge, UFEL broadened the understanding of causal factors underlying occurrences which previously were treated as problematical by environmental engineers. A similar approach was adopted by the USBM who developed METHPRO to assist US mine operators resolve methane control problems. An expert system for the evaluation and reduction of methane explosion risk has been developed in Spain (Alarcon and Silva, 1990). The program is understood to use probabilistic methods to assess risks rather than provide guidance on engineering solutions.

Expert Systems do not replace the human element. The success of even simple applications comes from ensuring that all the relevant questions are asked for a particular problem thus minimising oversights. Expert systems do not necessarily provide the best response to all situations. In some instances, the requirements of a mine may be better served by written technical guidance or specialist training.

Summary Of Methane Emission Prediction

Methane prediction methods have been developed for application to underground longwall methods of working. The methods are largely empirical, some, such as the MRDE method, having a theoretical basis but all apparently successful in their countries of origin. Knowledge based computer programs have been developed to guide the treatment of methane emission problems which are not easily represented by mathematical models.

APPENDIX 2
Comparisons of gas drainage methods

Method	Description	Advantages	Disadvantages
Pre-drainage using vertical surface boreholes	Involves fracturing one or a series of seams using high pressure fluids. The fractures are held open by injecting a support material. Thus, gas and other fluids, able to flow through the coal seam, can enter the borehole without being limited by the resistance of the surrounding coal. Other methods of borehole completion are also used. One involves the formation of a cavity in the production zone.	• Gas removed in advance of mining. • High purity gas of commercial value usually obtained. • Removal of gas independent of underground mining activities. • When hydrofractured coal worked through, roof conditions not usually adversely affected. • Can sometimes be converted to gob wells after mine-through. • An opportunity to reduce emissions of firedamp to the atmosphere (reduction of greenhouse gas emissions) from coal mine related sources. • Can be operated independently of mining operations. • No specialised underground firedamp drainage equipment and drillers required.	• Costly to complete. • Surface collection pipelines needed to facilitate utilisation. • Surface arrangements may be difficult in terms of ownership, access and visual intrusion. • Disposal of saline water which is sometimes produced. • Permeability may be too low in deep seams. • Drilling costs may be prohibitive for deep coal seams. • The coal seams must have a high natural fracture permeability. • Difficult to co-ordinate with the mining plan. • Design of borehole completion is a specialised task.
Pre-drainage using horizontal in-seam boreholes.	Long boreholes are drilled from underground roadways, or the base of shafts, into future areas of coal working, and gas is extracted over an extended period of time to reduce gas flows into driveages and future longwall coalfaces.	• Gas removed in advance of mining. • High purity gas is produced suitable for utilisation. • Gas drainage independent of coal extraction operations. • Less costly than drilling vertical boreholes from the surface. • Applicable in deep mines. • Can reduce outburst risk in seams that are outburst prone. • Allows high development rates in gassy headings. • Most effective where there are few, or no coal seams within about 100m of the roof or floor of the worked seam.	• Boreholes need drilling in advance of mining. • The coal seam must have a moderate to high natural permeability to facilitate a significant reduction in seam gas content over a reasonable period of time. • Reduces gas emission from the worked seam but not from adjacent seams disturbed by longwall mining. • Water emissions, borehole stability and directional control of drilling can be problematic in some seam locations. • Trained, underground team of firedamp drillers required.
Precautionary pre-drainage using shortholes in the roof of headings.	Short, vertical boreholes are drilled into roof strata in headings to control firedamp emissions from discrete fractures in sandstone roof strata. The gas may flow from a coal seam above and in contact with the fractured strata or it may occur naturally in the sandstone. Low-angle boreholes are sometimes drilled in the roof ahead of the face to release the gas in advance of mining reducing frictional ignition risks in mechanised driveages.	• Low cost method for reducing frictional ignition risks and controlling firedamp emissions.	▪ Low gas flows ▪ Firedamp drainage system connections if considered necessary.
Post-drainage using cross-measure boreholes.	Boreholes are drilled at an angle above or below the goaf from the return airway of a longwall face and connected to a firedamp extraction system. In some retreat longwall mines, better drainage performance has been obtained from boreholes drilled behind the face compared with those pre-drilled in advance of the coalface. Access behind retreat faces is, however, sometimes difficult to maintain and in some countries is prohibited.	• High captures possible on advancing longwall coalfaces. • Practicable for deep coal seam workings. • Short drilling distance to primary gas source. • Gas can be extracted and piped to a common, fixed surface location for commercial exploitation or use on the mine site. • Effective in low-permeability coal seams. • Floor boreholes can reduce the risk of sudden emissions of gas in susceptible workings. • Flexible and easily modified drilling pattern. • Least costly of the gas drainage methods per metre of borehole.	• High capture efficiencies difficult to sustain on retreat faces. • For maximum effectiveness need to be drilled behind the face on retreat longwalls where access may be restricted. • The productive life of boreholes is generally short. • Gas of medium to low purity is obtained due to ventilation air being drawn into the gas extraction system through mining-induced breaks in the strata. • Trained, underground team of firedamp drillers required. • Underground pipeline infrastructure needed to the surface or to a safe discharge location in a return roadway.

Method	Description	Advantages	Disadvantages
Post-drainage using surface goaf boreholes.	A venting borehole is drilled and cased to within a short distance of the seam to be worked. Casing in the bottom, productive length of the borehole is usually slotted. Sometimes a borehole is drilled and cased to 30m above the seam and then a smaller diameter open hole drilled through the worked seam horizon before or after the coalface has passed. A safe and reliable method of placing the borehole involves drilling to intersect the worked seam and then grouting the bottom 30m.	• Gas drainage operations independent of underground operations. • Capable of venting substantial firedamp flows from longwall goafs. • Well proven, cost effective method at shallow to moderate depths. • High purity gas is obtained in many instances. The productive life can extend to several months. Surface extraction fan or pump not always necessary. • Can respond to changes in the mining plan. • No specialised underground firedamp drainage equipment and drillers required. • Lower cost than pre-drainage from vertical hydrofractured surface boreholes.	• Costly for deep coal seams. • Risk of water inflow where major aquifers overlie the worked coal seam. • No direct gas drainage of seams in the floor of the workings. • In mines with main exhaust ventilation, goaf boreholes cannot be operated until coalface has passed some distance beyond the borehole. • Collection of gas for exploitation requires costly surface pipeline infrastructure. • Only applicable where there are no surface access constraints. • May tap and vent more gas than would be released into underground workings and, if the gas is not collected, the quantity vented to atmosphere may be greater than with an underground drainage method.
Post-drainage using horizontal longholes above or below the worked seam.	A number of boreholes are drilled in a competent horizon at say 20m to 30m above, or below, the worked seam for the full length of a projected longwall panel. If no drilling site is available at the appropriate horizon, the borehole is steered to the requisite level from the mined horizon.	• In appropriate geological situations can be used to pre-drain a seam adjacent to the mined seam before providing a goaf post-drainage facility. • Potentially higher capture efficiency than with cross-measures boreholes drilled from the mined seam. • Gas drainage activities separate from coal production activities. • High purity gas can be obtained. • Captures gas from close to initial release sites near the line of the coalface.	• Guided longhole drilling relatively costly. • Steered drilling problematic in some strata conditions. • Repair of collapsed or damaged boreholes difficult. • Inflexible to changes in mining operations. • Reliant on the accuracy and speed of drilling to ensure a satisfactory system is in place before coal production starts. • Specialist underground drilling skills and equipment needed. • Special drilling fluids used to support borehole may reduce the permeability of the walls to gas.
Post-drainage from underlying or overlying roadways.	A roadway is driven above or below the worked seam prior to mining. The heading is then stopped off and connected to the firedamp drainage system via a pipe through the stopping. The area of influence of the drainage heading can be increased by drilling fans of boreholes from it prior to sealing.	• Can be complemented by cross-measures drilling from the gallery. • Potentially higher gas capture efficiency than with cross-measures boreholes drilled from the mined horizon. • Gas drainage activities separate from coal production activities. • Existing roadways or old workings above, or below, the proposed coal production district can sometimes be used removing the need for a purpose constructed drainage gallery. • High purity gas can be obtained.	• Costly to drive access from the worked seam to the gallery level. • In spontaneous combustion-prone coal seams, a ventilation short-circuit through fractured ground to the gallery could lead to heating of the coal, necessitating cessation of gas drainage. • Costs could be prohibitive unless the gallery is driven in a reasonably thick coal seam. • Inflexible to changes in mining operations. • May be ineffective where strong, competent strata are present between the drainage roadway and the longwall face.
Post-drainage from chambers or pipes in longwall goafs.	A chamber is constructed in the goaf behind the face and connected through stoppings to the mine firedamp drainage system. Alternatively, a firedamp drainage pipe with an open end near the face start line is extended as the face retreats	• Reduces concentrations of firedamp at the return end of a retreat longwall face. • Gas quantity entering the district reduced.	• High capacity firedamp drainage needed due to the low gas purity captured. • Captured efficiencies usually low. Only low suction can be applied and therefore the zone of influence is very small. Not always effective in gassy mines. ▪ Low volume of gas captured.
Post-drainage from cross-cuts into the longwall goaf (variant of the above method).	Cross-cuts are driven from a parallel road alongside the working district to intercept the goaf. The mine firedamp drainage system is connected to a pipe through a stopping constructed in the cross-cut. Where access and strata conditions permit, boreholes could probably be drilled instead of driving cross-cuts.	• May reduce the need for cross-measures firedamp drainage drilling in some circumstances. • Gas drainage activities are independent of coal extraction activities. • Reduces concentrations of firedamp at the return end of the longwall face.	• High capacity firedamp drainage needed due to the low gas purity captured. • Capture efficiencies likely to be low in many instances. • Only practicable where a suitable roadway exists from which cross-cuts to the goaf can be developed. • Cost of additional cross-cut driveage. • Captured gas may be unsuitable for utilisation without natural gas enrichment.

APPENDIX 3

CASE STUDIES

These case studies describe situations which have been solved by application of existing knowledge and techniques with some innovation but no novel technologies. A fundamental lesson appears to be that firedamp drainage performance can invariably be improved through good housekeeping, attention to detail, regular monitoring and systematic drilling. All of these factors relate to firedamp drainage management.

Case Study 1: Improving Capture Efficiency In A Gassy Longwall District

Problems were being experienced on a retreat longwall due to methane concentrations in the district return compromising planned coal production. Ventilation quantities had been increased but no further improvement was practicable. Firedamp capture efficiencies of around 50% were being achieved but 60% was needed to facilitate the required coal production. The strategy adopted involved shortening back two district ranges behind the face and using the third range as a collector (sewer range) to which the isolated ranges were linked with hoses and control valves. Thus, as capture from holes near the face start line declined, increasing suction could be applied to the most productive boreholes close to the face.

Drainage boreholes were cased to the base of the first significant coal seam at some 11m to 16 m above the workings. Boreholes were drilled at angles of 60° and 70°, both being initially successful. However, borehole life was short with substantial loss of purity occurring in the region 10m to 20m behind the chocks. The number of productive boreholes behind the face line typically varied from 3 to 5. Investigation with probe rods indicated that boreholes in which purity had been lost were usually sheared within the standpipe length. The fundamental problem was considered to be roof instability in the vicinity of the boreholes.

Factors of possible relevance included:

- The position of the borehole relative to the goaf edge
- The local geology
- The roof support system

The following immediate actions were proposed in response to the problem:

- Strengthen roof support on the goaf side of the back-return
- Seek advice from a strata control specialist

Various strata control options for improving borehole support were considered including different timber pack configurations, steel supports or roof bolting. Previous faces had used a coal pillar system to form the back-return. A coal pillar was considered among the other strata control options and was attempted without success for a short while.

An inspection of the conditions was made by a strata control specialist. Initial evidence suggested borehole failure was due to inadequate strength of packs on the goaf side leading to stepwise migration of goaf fractures across the return roadway. The shear stresses developed were probably responsible for dislocating the standpipes. Stabilisation of the goaf edge with stronger support possibly complemented by cable bolting in the roof were considered as a remedy. A programme of geotechnical monitoring, including instrumentation of firedamp drainage standpipes was therefore undertaken leading to a re-design of the timber packs. *Linklok* blocks were introduced at the waste edge and hardwood packs used in the gateroad.

Case Study 2: A Major Gas Emission From Old Workings

Active coalfaces often pass beneath old workings. Generally, the effect is a reduced gas flow due to the removal of the gas source and degassing effects associated with the former working. Sometimes, residual voids in old workings can be gas-filled and in certain circumstances unusually high emissions can occur. In this instance, early in the life of the longwall district methane concentrations in the tailgate increased to 2% and showed no sign of decreasing when coal production was halted.

A fault zone intersected by the face start line was considered to represent the most likely pathway introducing the gas to the district.

Initial results from contacting the old workings, some 50m above, were inconclusive but eventually a reproducible static pressure measurement was obtained and the presence of high purity gas at a pressure of 79kPa confirmed.

The option of drilling a surface borehole for accelerating the removal of hazardous gas from the old workings was discarded due to time, planning, access, depth and drilling constraints. The lowest risk solution was considered to involve underground drainage.

The method for achieving control of the nuisance gas in the overlying workings involved reducing the pressure of the gas as rapidly as possible in a safe manner. A negative pressure of 6 kPa was eventually attained in the old workings preventing further extraneous gas flows entering the production district and providing a drainage roadway in the roof strata to supplement conventional district firedamp drainage.

The solution involved installing:

- Large diameter vertical boreholes into the old workings to accelerate degassing
- Methane drainage ranges to the degassing boreholes and
- Increasing the firedamp drainage capacity of the mine

It was important to maintain the momentum of drilling new boreholes and applying a high standard of care and attention to the firedamp drainage infrastructure. The ultimate measure of continuing improvement was a declining gas pressure in the overlying old workings. Gas flow monitoring was an important tool for evaluating drainage performance both as new boreholes were added and also as the drive pressure was progressively reduced.

Rates of pressure reduction initially averaged about 2.4kPa per day decreasing to 0.9kPa per day as pressure fell from 5kPa to minus 6kPa. Methane concentrations in the tailgate ranged from 0.5% to 1.5% once coal production was re-established.

ANNEX 1

Handbook on the effective design and management of firedamp drainage for UK coal mines

Prepared by Wardell Armstrong
for the Health and Safety Executive

Dr David P Creedy
BSc (Min Geol), MSc, PhD, CEng,FIMM
Kevin Garner
CEng, FIMM
Wardell Armstrong
Lancaster Building
High Street
Newcastle-under-Lyme
Staffordshire
ST5 1PQ

ACKNOWLEDGEMENTS

We are indebted to RJB Mining (UK) Ltd and Tower Colliery Ltd without whose generous assistance this research could not have been undertaken. Steve Denton, HSE, and W Tonks, Coalgas (UK) Ltd deserve special thanks for their help in preparing this document.

FOREWORD

This guidance document was prepared as part of a research project commissioned by HSE following a submission by Wardell Armstrong to the “Competition of Ideas”. The work was undertaken between 1 November 1999 and 30 September 2000. The principal aims of the research project were to review the state-of-the-art of methane drainage and its application in UK coal mines, and to provide recommendations on safety enhancements and further research requirements to HM Mines Inspectorate. A literature search formed the basis for a worldwide review of both methane drainage methods and recent research. The guidance was developed from an analysis of current UK firedamp drainage practice on longwall retreat coalfaces based on observations made, and information obtained, during visits to Maltby, Thoresby, Welbeck and Kellingley collieries. Findings at these sites were combined with results of studies at Tower colliery. The guidance, although not mandatory, is consistent with current mining legislation and is essential reading for mine managers wishing to achieve compliance.

CONTENTS

1. INTRODUCTION

1.1 FIREDAMP DRAINAGE

Firedamp drainage is a technique for capturing gas released during coal mining operations before it can enter the airways. This document aims to provide mine managers with a policy and organisational framework within which firedamp drainage systems can be systematically planned, operated and audited in accordance with the requirements of current mining legislation.

1.2 FIREDAMP

The gas found naturally occurring in coal seams is known as firedamp. The principal constituent of firedamp is methane (typically 80% to 95%) with lower proportions of ethane, propane, nitrogen and carbon dioxide. Firedamp is potentially explosive when confined in concentrations around 5% to 15% in air at normal pressures. As methane is the predominant constituent of firedamp, the two terms are sometimes used interchangeably for practical coal mining purposes. Other terms in common use are coalbed methane (CBM) and "gas".

1.3 THE IMPORTANCE OF EFFECTIVE FIREDAMP DRAINAGE

Underground operations at most collieries in the UK depend on the effectiveness of firedamp drainage to provide and maintain a safe working environment. Firedamp drainage techniques are used, together with mine ventilation, to control gas emissions in longwall districts allowing planned coal production rates to be achieved safely. The consequences of failure are potentially hazardous working conditions and an increased explosion risk. Practical difficulties can be reduced by effective design and management which requires a sound understanding of the basic scientific and engineering principles underlying firedamp drainage in mines.

Firedamp drainage requirements may vary over the life of a production district and also from day to day, due to changing mining and geological conditions. Problems can develop with borehole drilling, gas capture rates and drainage infrastructure. Such difficulties need to be identified and resolved as soon as possible. Monitoring of gas flow, purity and pressure is therefore essential at individual boreholes, district and outbye ranges, and at the firedamp extraction plant.

As well as improving safety, effective firedamp drainage can reduce ventilation costs (through reduced ventilation requirements), downtime costs, coal production costs, infrastructure development costs and also increase accessibility to the coal resource and reduce dust pick up (due to lower ventilation velocities). Mines can use the captured firedamp as an energy source, reducing overall energy costs and, at the same time benefiting the global environment by reducing atmospheric emissions of greenhouse gases. Safety should always take precedence over gas exploitation and conflicts would not be expected with a well-managed system.

2. BASIC PRINCIPLES

Those responsible for the planning and operation of firedamp drainage systems should have a basic understanding of the occurrence of gas in coal seams, emission processes and gas capture methods.

2.1 OCCURRENCE OF FIREDAMP IN COAL SEAMS

Firedamp was formed in coal seams as a result of the chemical reactions taking place as the coal was buried at depth. Some of the gas dissipated into the pores of surrounding rocks and some migrated into geological reservoir structures.

The gas contents of coal seams tend to increase with vertical depth in a strata succession. In general, gas content also tends to increase with coal rank.

Firedamp can be detected in many sedimentary rocks but generally in low concentrations. It occurs in much higher concentrations in coal rather than in any other rock type because of the "adsorption" process that enables gas molecules to be packed into the coal substance to a density almost resembling that of a liquid. Gas contents of coal seams worked in the UK range from less than 1 m^3/tonne up to around 15 m^3/tonne.

2.2 FIREDAMP EMISSION PROCESSES IN COAL MINES

Deep coal in the UK is generally extracted by means of a retreat longwall mining method typically involving two parallel access roads, up to 300m apart, linked by the coalface.

Firedamp is emitted from the coal exposed on the coalface, and from coal broken by the cutting machine and conveyed out of the mine. As each strip of coal is removed, the face supports are moved forwards allowing the unsupported area (‘waste’, ‘gob’ or ‘goaf’) left behind to collapse. A consequence of the caving is that seams above and below the worked horizon are destressed and release gas.

Longwall caving can destress strata from 160m to 200 m above and down to 40m to 70m below the worked seam. Any firedamp bearing strata within the disturbed zone will release a proportion of their gas which will then flow towards the workings (Figure 1). The extent of the destressing may be reduced where strong beds are present in the strata which carry the stress. Seams lying 40m or more below longwall workings may not always release significant gas flows. Table 1 shows the principal factors affecting the gas release process.

Table 1
Factors affecting gas release

Rate of gas release	Extent of disturbed zone
• Gas contents of the coal seams • Number and thicknesses of seams in the disturbed zone • Proximity of the seams to the worked seam • The age of the district (area of goaf) • Rate of coal extraction	• Height and length of working coalface • Strata strengths • Previous working, above and below the worked seam

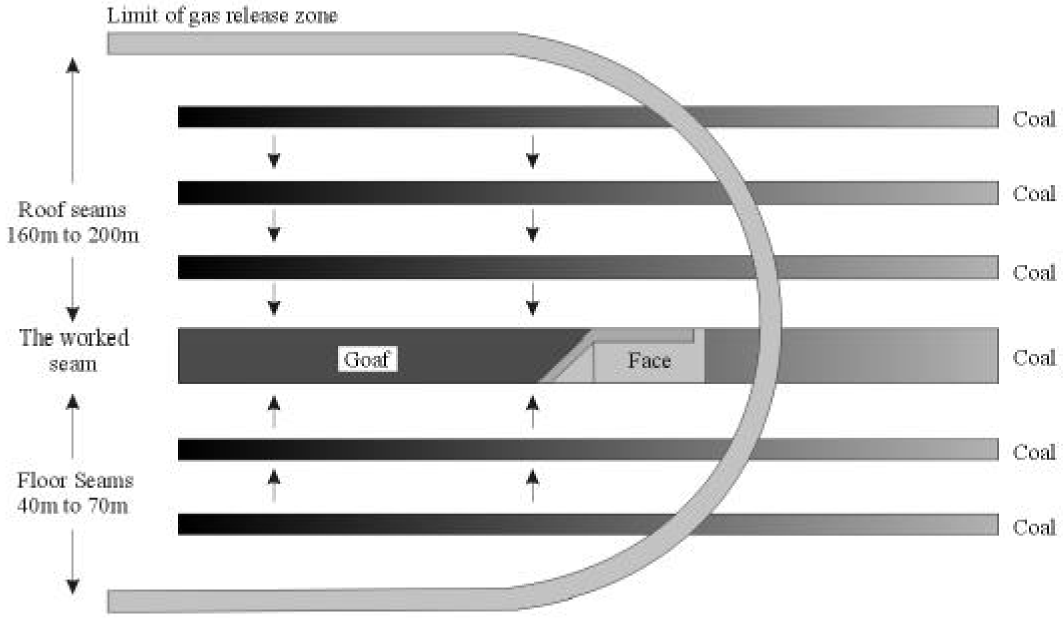

Figure 1 Gas emission in longwall workings

In addition to the gas released from coal seams, gases can also be released from conventional sandstone reservoirs when they are disturbed by mining activity. Gas can also be introduced onto a district in the ventilation air when outbye sources of pollution are present, such as old workings adjacent to an intake, particularly during rapid falls in barometric air pressure.

Table 2 shows the situations in which unusually high gas emissions can occur.

The gassiness of a longwall district, or a whole mine, can be expressed as a 'specific emission.' This quantity represents the volume of firedamp released into the mine per tonne of coal extracted. Gas flows from seams above and below the workings do not respond immediately to changes in coal production rate, building or decaying gradually when production rate rises or slows. To obtain a reasonable estimate of specific emission, flow data are averaged over a long period of time (at least a few months and ideally one year).

Table 2
Unusual emissions of gas

Type of emission	Occurrence	Trigger	Prevention
Rapid or sudden emissions from the floor	Strong bed overlying a coal seam within 60m of the working floor horizon	Any change in stress distribution caused by changing thickness of the strong bed or intervening strata in the floor, goaf and pillar boundaries in the roof, minor faults and the "square" position (ie., length of worked panel equals the face length)	Regular floor boreholes, within 20 m of the face to prevent gas pressure build up beneath the strong bed. Floor boreholes may be needed in both gates where the risk is acute.
Outbursts	Sudden release of firedamp and coal, or other rock, into the workings.		Not currently experienced in any UK mines.
	Hazardous hydrocarbon emissions from petroleum sources.	Approach to petroleum bearing structure.	Cease development if hexane in the general body exceeds critical concentrations.
Other emissions	Conventional natural gas reservoirs (fault bounded, fractured or permeable bed) within the zone of disturbance of a longwall face (typically up to 150 m above) or abandoned mine workings containing gas at high pressure in dry, open voids (up to 150 m above).	Longwall caving leading to a greater inflow of gas than would be expected solely from coal seam sources. The situation can be exacerbated where faulting provides a discrete low resistance pathway.	Plan for additional firedamp drainage.

2.3 FIREDAMP CAPTURE METHODS

The methods used for capturing firedamp in coal mine workings are classified as either pre-drainage or post-drainage methods depending on whether gas is drained from virgin coal before mining (pre-drainage), or drained from the goaf created by longwall extraction (post-drainage). Pre-drainage methods are only effective when applied to seams of high permeability. There are few highly permeable seams in the UK coalfields but the method should be considered where they exist.

UK coal mines use the post-drainage, cross-measures method of draining firedamp. Boreholes are drilled in coalface return roadways close to the face at an angle above, and also in some instances below, the goaf. The holes are linked by flexible hoses to a pipe range. Pumps sited on the surface or below ground draw the gas to a safe discharge point or surface utilisation plant.

On advancing coalfaces, boreholes are drilled just behind the face line (Figure 2).

On a retreating coalface, boreholes should, wherever possible, be drilled behind the face line (Figure 2). In order to achieve this, specific support and ventilation arrangements are needed to enable the boreholes to be drilled safely. Poor roof conditions, or floor lift behind the face can create access difficulties and delay borehole installation. To avoid the access problem and ensure a safe drilling environment, boreholes can be pre-drilled from the return roadway ahead of the face (Figure 2) but capture efficiencies are usually less than for holes drilled behind the face due to damage caused by high stresses when the face passes.

However, even when boreholes are drilled behind the face, firedamp drainage capture efficiencies still tend to be less on retreat faces compared with advancing faces because the producing boreholes cannot always be monitored, adjusted or maintained once they are more than 15m to 20m behind the face. Capture efficiency can be improved by extending the distance behind the face that is ventilated, and hence increasing the number of holes that can be safely accessed. The boreholes on an advancing face remain accessible and available for the full life of the district.

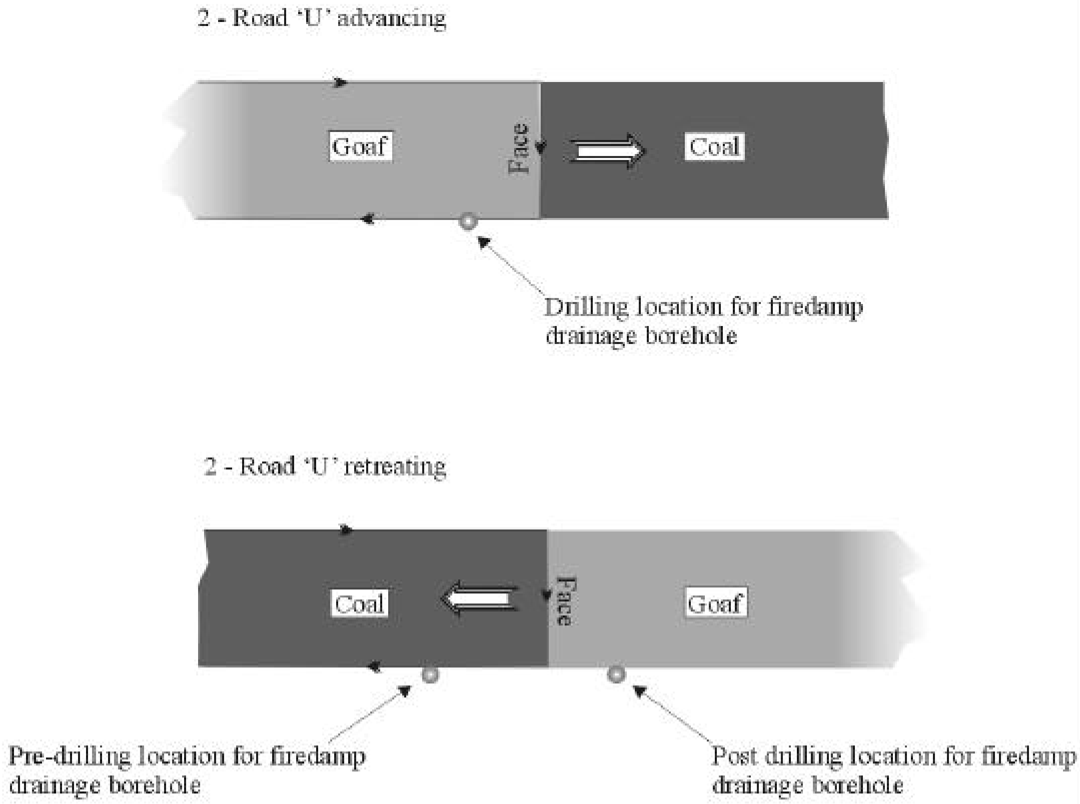

Figure 2 Longwall face layouts showing firedamp drainage drilling locations

Cross measures drainage in retreat districts is sometimes supplemented by goaf drainage where gas is extracted from behind a seal near the face start line and fed into the firedamp drainage collection pipework. However, the capture efficiency is generally low due to the low purity of the gas captured.

Another technique is to vent the gas from the rear of the goaf, via a specially driven or pre-existing roadway, into the main airstream where it is diluted to below statutory limits. As a result, firedamp drainage may no longer be necessary, or the required capture efficiency can be reduced. Irrespective of the drainage capture efficiency required, there must be a robust management scheme in place to ensure consistent results.

3. FIREDAMP DRAINAGE SAFETY MANAGEMENT STRUCTURE

Firedamp drainage is practised to ensure the safety of mining operations. An effective management structure is necessary to ensure good practices are employed which comply with all relevant mining legislation. A suitable framework is shown in Figure 3 and discussed below.

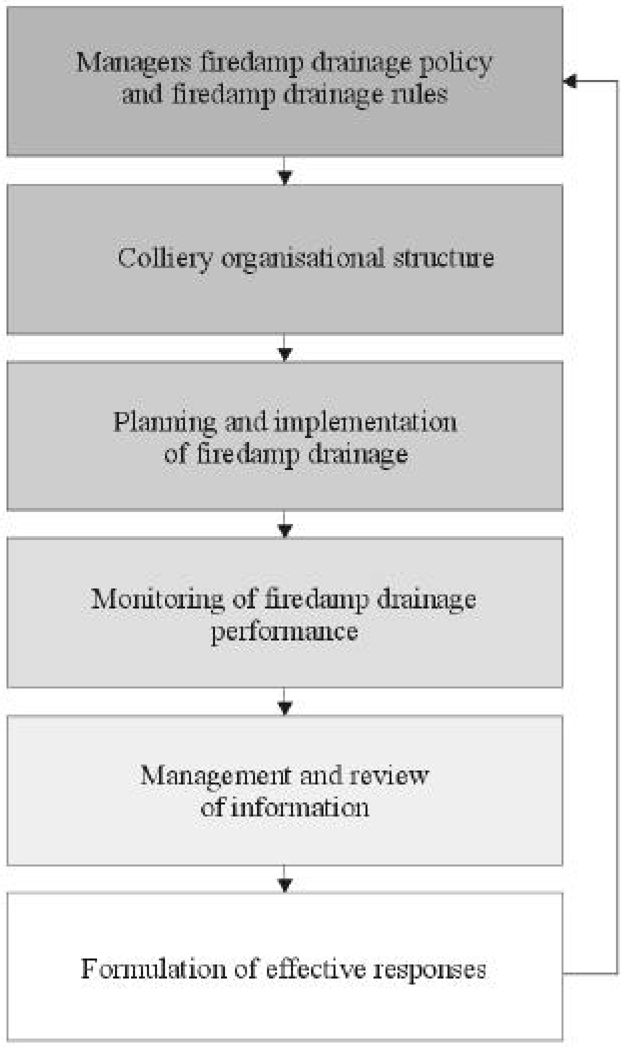

Figure 3 Safety management of firedamp drainage

3.1 LEGAL REQUIREMENTS

The legislative framework for health and safety at mines comprises of the Health and Safety at Work Act 1974 together with across-the-board regulations which apply at mines as well as to other premises, and specific mining legislation which applies only at mines.

The law relating to firedamp drainage and ventilation in mines is currently under review as part of the Health and Safety Commission's review of mining legislation. Whilst the detail may change, the underlying principles will remain the same.

The Health and Safety at Work Act requires mine owners as employers to ensure that systems of work in their mines are safe. General regulations require employers to carry out risk assessments and to provide suitable equipment and ensure its safe use. In addition, there are some specific mining regulations relevant to the effective design and management of firedamp drainage systems, in particular:

- The Coal Mines (Firedamp Drainage) Regulations 1960
- The Coal and other Mines (Ventilation) Regulations 1956
- The Management and Administration of Safety and Health at Mines Regulations 1993
- Reporting of Injuries, Diseases and Dangerous Occurrence Regulations 1995
- The Electricity at Work Regulations 1989

3.1.1 The Coal Mines (Firedamp Drainage) Regulations 1960

These regulations apply to the capture and safe disposal of firedamp before it has been diluted by air. They require:

- Precautions when drilling firedamp drainage boreholes including the use of a ‘stuffing box’
- Provision to measure gas flow at each hole
- Sealing of standpipes
- Use of flexible hoses for connecting holes to ranges
- No ranges in intake shafts
- Provision for dewatering and firedamp sampling in ranges
- Adequately supported ranges with yellow bands at joints and yellow valves
- Air ingress to be minimised when connecting holes
- Use of approved pumps for firedamp extraction
- Safety provisions in the methane plant
- Precautions at firedamp discharge locations
- Competent supervision of methane plants

3.1.2 The Coal And Other Mines (Ventilation) Regulations 1956

These regulations specify where, how and when firedamp concentrations should be measured. They also require that approved firedamp detectors are used and specify how they should be deployed.

3.1.3 Other Technical Regulations

Other regulations require notification of dangerous occurrences such as gas ignitions at the surface methane plant, gas outbursts and inrushes of gas from old workings. Electricity regulations specify maximum airway methane concentrations at which the electricity supply should be switched off and the conditions that must be present before power is restored. Consideration should be given to the security of electricity supply when selecting an underground site for methane pumps.

3.1.4 The Management And Administration Of Safety And Health At Mines Regulations 1993 (MASHAM)

MASHAM requires mine owners to appoint managers before a mine can legally be worked. It also requires mine owners to ensure their mines are managed and worked in accordance with the relevant statutory provisions.

The owner and manager have a duty to establish a management structure which is set down in writing to include suitably qualified and competent persons to assist the manager in the performance of his statutory duties. These appointments, together with the managers policy, should include provisions for the effective management and control of firedamp emissions. Specialist technical assistance can be sought from the owner's wider organisation or from external consultants, but this does not detract from the responsibilities of those in the official management structure.

3.2 GENERAL FIREDAMP DRAINAGE MANAGEMENT PRINCIPLES

The mine manager should ensure there is a planned and systematic approach to implementing firedamp drainage through an effective health and safety management system.

Effectively managing firedamp to ensure safe working essentially means achieving a correct balance between having sufficient:

- Ventilation quantities to dilute and disperse firedamp entering the general body of mine air at all levels of planned coal production and, where ventilation alone is unlikely to achieve this
- Firedamp drainage to ensure no more gas enters the mine airways than can be diluted to below statutory limits by the available ventilation air

In order to achieve this effectively mine owners and managers need to ensure that:

- There is a clear firedamp drainage policy
- Within the organisation there is a clearly defined chain of command in relation to firedamp drainage
- Procedures which will ensure the effective management and control of firedamp emissions are clearly set out in managers rules
- There is a disciplined approach to design and implementation of measures
- Those in the management structure with responsibilities for firedamp drainage and those in the workforce carrying out the measures understand the basic principles of firedamp capture
- Suitable training is provided where necessary
- Effective supervision is provided
- Sound, basic operational standards are set, reviewed and maintained
- Technical support is available from specialists as required
- Suitable measuring equipment is provided
- Monitoring is carried out and the results disseminated and acted upon
- Firedamp drainage policy, organisation, planning and operational performance is subjected to audit and review

3.3 POLICY

An effective health and safety policy sets out clearly what the owner and manager intend to do in relation to firedamp drainage and what they intend to achieve. A firedamp drainage policy should be developed which establishes a strategy for planning, assessment, design, installation, commissioning, operating, monitoring and review of the firedamp drainage system. Table 3 outlines an example of a policy.

Table 3
Managers' firedamp drainage policy

The owner and manager will provide and maintain an effective firedamp drainage system. In order to achieve this they will: • Develop a firedamp drainage management organisational structure • Appoint persons to undertake specific management and functional roles • Identify and apply best practice firedamp drainage methods • Specify the required drainage capture (or pure drained flows) • Specify the general location from which boreholes are to be drilled • Provide necessary training resources • Identify sources of external specialist technical assistance • Seek continuing improvement in management and operational effectiveness by encouraging staff and worker contributions and through the implementation of an audit and review process

3.4 ORGANISATION

A key part in effective management is the provision of clearly defined roles and responsibilities for those in the management structure (Table 4) who have to deliver the policy. The organisational structure should encourage staff involvement. The roles defined in the organisational structure must be undertaken by a competent person, but a person can undertake more than one role if competent to do so.

Table 4
Colliery organisation

The Manager should appoint persons: • To have overall management responsibility for the implementation of the Managers' firedamp drainage policy and, in particular, the development and management of the Firedamp Drainage Rules • To be responsible for the day to day management of firedamp drainage operations in the working districts • With specific responsibility for planning, design and management of the underground environment. In addition, responsible for organising training in firedamp drainage practises and awareness • With specific responsibility for the installation and maintenance of all firedamp drainage equipment including the gas extraction plant. • With specific responsibility for firedamp drainage monitoring and control, reporting to the line manager and responding to the operational requirements of the senior district official • To Whom It May Concern: prepare firedamp drainage plans, borehole geometry plans and to record borehole positions and configurations • With responsibilities for liaison with firedamp drainage design staff to ensure consideration of firedamp drainage requirements in designing face-end support systems

3.5 PLANNING

Firedamp drainage is an integral part of the mining operation and should be planned and managed accordingly.

The firedamp emission hazard can be mitigated by good planning. Planning involves assessing the gas hazards and then designing control measures which are implemented as operational procedures to mitigate the risks. The necessary procedures should be described in the manager's firedamp drainage rules examples of which are shown in Table 5.

Table 5
Firedamp drainage rules

The firedamp drainage rules set out the procedures required by law or by the firedamp drainage policy. They should require:

- Safe systems of work for installation, commissioning, maintenance, operation and monitoring of the firedamp drainage system
- Routine inspection of the system
- All equipment in the firedamp drainage system, including drilling equipment, to be included in the manager's planned, preventative maintenance scheme
- Preparation of a firedamp drainage plan of the mine and a schematic plan of the drainage plant
- Procedures for draining gas from old districts with actions based on a 5-day barometric pressure forecast (upgraded daily)
- Measurement and monitoring
- Recording and reporting of results
- Review and appraisal of system performance

The aim is to plan to minimise risk where possible through the selection and design of working methods, equipment and processes, identifying specific actions required to promote a positive health and safety culture.

Firedamp emission is only one of a number of underground environmental hazards which might impact on the health and safety of the workforce. At the coalface design stage, firedamp drainage requirements should therefore be considered in conjunction with spontaneous combustion, dust and heat related risks.

Planning firedamp drainage systems will involve:

- Appraisal of previous experience of gas emission, particularly in the same seam
- Examination of geology and past mining
- Examination of mining and development plans
- Study of the mine ventilation layout (by reference to mine ventilation plans and records)
- Firedamp emission prediction
- Assessment of potential for unusual gas emissions
- Determination of required capture efficiency
- Review of working methods and face design
- Design of face-end strata control requirements
- Design and specification of a drainage scheme
- Specifying monitoring requirements

Information relevant to the planning of firedamp drainage needs, both present and future, can be obtained at all stages of the mining process from exploration, technical specification, operational performance, monitoring and review.

3.6 MONITORING

It is essential to monitor the performance (firedamp drainage capture efficiency) of the system to determine whether or not it is performing as planned and in accordance with the manager's firedamp drainage rules.

Advances in environmental monitoring technology should be exploited to ensure effective use of the large amounts of data collected and to provide key staff with visual displays of firedamp drainage management information.

3.7 AUDITING AND REVIEW

There should be a regular, systematic review of firedamp drainage performance based on routine and other monitoring data as identified in the firedamp drainage rules. Performance is assessed by review of key performance indicators and also by comparison with good practice elsewhere. The performance of the mine firedamp drainage operations should be recorded in the annual report.

If audits indicate deficiencies in the effectiveness of firedamp drainage management then the policy, organisation, rules (procedures) or monitoring regimes should be amended as necessary. Audits should be carried out annually by a competent person who is external to the firedamp drainage management organisation of the mine.

An effective and responsive management team can deal with unexpected difficulties as illustrated by the case study in Box 1. A high gas emission was encountered which halted coal production. External advice was sought and a strategy developed to control the hazard and enable coal production to be restored. On review, the need for changes in firedamp drainage planning was recognised and procedures were subsequently revised.

Box 1
Case study: A major gas emission from old workings

Active coalfaces often pass beneath old workings. Sometimes, residual voids in old workings can be gas-filled and in certain circumstances unusually high emissions can occur. In this instance, early in the life of the longwall district, firedamp concentrations in the tailgate increased to 2% and showed no sign of decreasing even when coal production was halted. A fault zone intersected by the face start line was considered to represent the most likely pathway introducing the gas to the district.

Initial results from contacting the old workings, some 50m above, were inconclusive but eventually a reproducible static pressure measurement was obtained and the presence of high purity gas at a pressure of 79kPa confirmed.

The method for achieving control of the nuisance gas in the overlying workings involved reducing the pressure of the gas as rapidly as possible in a safe manner. The solution involved installing:

- Large diameter vertical boreholes into the old workings to accelerate degassing
- Firedamp drainage ranges to the degassing boreholes; and
- Increasing the firedamp drainage capacity of the mine

Rates of pressure reduction initially averaged about 2.4kPa per day decreasing to 0.9kPa per day as pressure fell from 5kPa to minus 6kPa. Firedamp concentrations in the tailgate ranged from 0.5% to 1.5% once coal production was re-established.

4. GOOD FIREDAMP DRAINAGE PRACTICE

The planning and operation of a firedamp drainage system is an evolving process along with the overall mine development. The necessary procedures to ensure good performance will be implemented through the firedamp drainage management structure.

4.1 ASSESSMENT OF HOW MUCH GAS MUST BE DRAINED

The principal aim of the assessment process is to identify the required performance of the firedamp drainage system.

The assessment process should identify by calculation the:

- Potential firedamp emission rate into the district for the planned level of output
- Dilution effects of the mine ventilation
- Effects of peak gas emissions
- Gas capture efficiency required

4.1.1 Prediction of firedamp flows

Likely gas flows should be predicted prior to the working of a district using a firedamp prediction method taking account of the factors shown in Table 6.

Table 6
Firedamp prediction imputs

• Depth and thicknesses (less dirt) of all coal seams within 200 m of the roof and 70m of the floor of the worked seam, and of any other gas-bearing strata • Proposed extraction parameters (face height, face length, ash content of coal, extraction rate, length of panel) • The gas content of the worked seams • The positions of old workings above or below the proposed panel to be extracted • Age of district

4.1.2 Maximum controllable gas flow

An increase in coal production rate will cause an increase in gas emission flow. However, there will be some level of coal production that cannot be exceeded as there is a maximum total district firedamp flow that can be controlled on a U-ventilated (Figure 2) longwall district. The maximum controllable flow (and also the limiting coal production) depends on:

- The statutory firedamp concentration limit in the return airway
- Airflow quantities that can be passed around the district
- The sustainable firedamp drainage capture that can be achieved, if firedamp drainage is available

The maximum air quantity may be limited by the quantity of air available, production district layout and environmental considerations.

When calculating the maximum controllable gas flow, the maximum peak level rather than mean levels of emission is used. Peak firedamp concentrations in the return airways of longwalls are usually around 1.5 times higher than the mean firedamp concentration. The air quantity required to dilute peak firedamp concentrations to within statutory limits is:

$$Q = \frac{0.15F}{C}$$

F is the pure firedamp flow rate (l/s)
Q the district air quantity (m^3/s), and
C is the maximum permissible firedamp concentration (%) in the roadway.

The above can be arranged in the form

$$Q = \mathrm{b}F$$

b is a constant with values of 0.12 and 0.075 corresponding to peak methane concentrations in the airway of 1.25% and 2% respectively.

The maximum controllable firedamp flow in a district is given by:

$$T = \frac{(100Q)}{\mathrm{b}(100 - D)}$$

T is the maximum controllable firedamp flow (litres/sec);
Q is the district airflow (m^3/s), and
D is drainage capture efficiency (%)

4.1.3 Efficiency of firedamp drainage capture

Firedamp released from the seam being worked cannot be captured. The firedamp drainage system will also be unable to capture all of the gas released from coal seams in adjacent strata. The capture efficiency is, therefore, always less than 100 per cent.

High gas captures may not be consistently obtained where the predominant coal seam gas sources lie in the floor strata rather than in the roof.

Typical capture efficiencies on longwall districts with cross-measures drainage are shown in Table 7.

Table 7
Typical firedamp drainage capture efficiencies

Type of longwall	Drilling location	Capture efficiency (%)
Advancing	Behind face	60 to 80
Retreating	Behind face	40 to 60
Retreating	Ahead of face	30 to 50

The firedamp capture efficiency of a gas drainage system in a particular longwall district is calculated from:

$$\text{Capture efficiency} = \frac{100\,F}{T}\ \%$$

F is the firedamp flow (l/s) in the drainage pipework (on a pure gas basis);
T is the total firedamp flow (l/s) in the airway (less any intake pollution) plus the drained firedamp (on a pure gas basis).

Gas capture efficiency is straightforward to calculate for a conventional "U" district but can be problematic to apply to districts with sewer roads, or where gas is drained independently of the working district, from workings above the seam.

4.2 How will the necessary capture be achieved?

The necessary capture is achieved by implementing and managing a methane drainage system that is designed having considered the following factors:

- Face-end ventilation arrangements
- Support systems at the return end of the face
- Firedamp drainage borehole configurations
- Drainage capacity and infrastructure requirements
- Installation and commissioning of drainage ranges
- Maintenance of the system
- Monitoring of boreholes, ranges and extraction plant
- Control of the firedamp drainage system

4.2.1 Retreat face-end ventilation arrangements

The health and safety of those drilling, monitoring and regulating firedamp drainage boreholes requires detailed consideration due to their potential exposure to gas emissions, heat and humidity.

Gas drainage is undertaken at the return end of the longwall face where ventilation is achieved by diverting relatively cool air from the face along the waste edge for a distance of some 10 to 20m before it is allowed to pass onto the rib side and enter the return. This arrangement, known as a back-return system, should be designed to ensure that potentially explosive gas mixtures are kept well back in the goaf by creating a pressure gradient which prevents high gas concentrations in the goaf from migrating towards the face-end as shown in Figure 4.

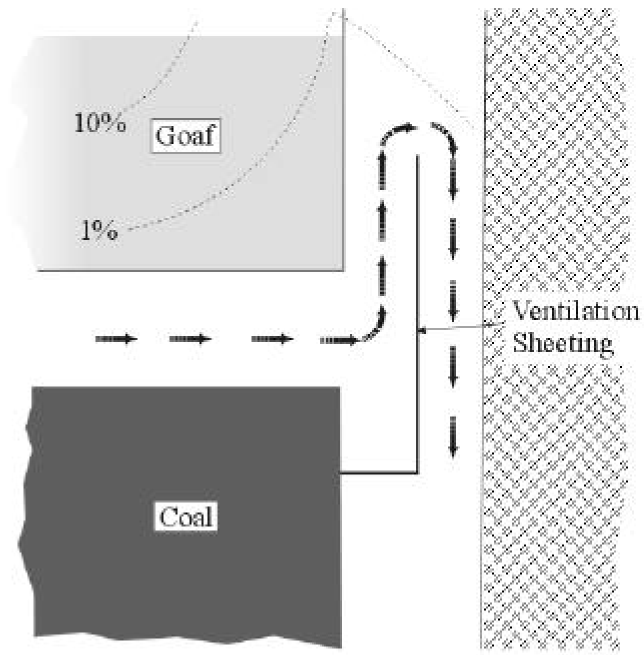

Figure 4 Control of gas concentrations by an effective back-return system

No stoppings should be constructed behind the face, on the return side of retreat faces, as high concentrations of firedamp can accumulate behind them, and may migrate onto the face as a result of ventilation or barometric pressure fluctuations.

Figure 5 shows how the ventilation arrangement is achieved by constructing a prefabricated curtain in the return roadway and Figure 6 shows an alternative method in which a narrow coal pillar is left at the face-end. The advantages and disadvantages of the two methods are compared in Tables 8 and 9.

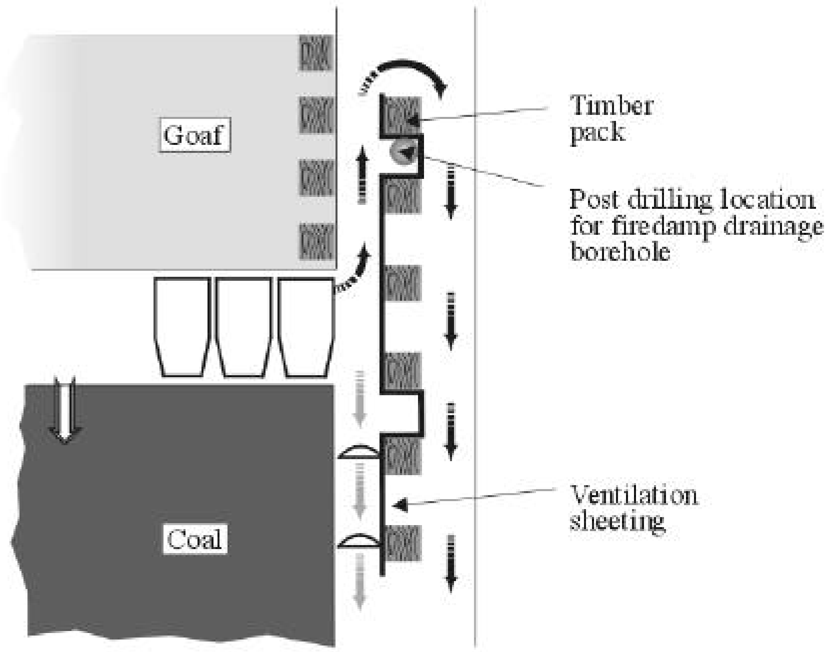

Figure 5 Pre-fabricated back-return system

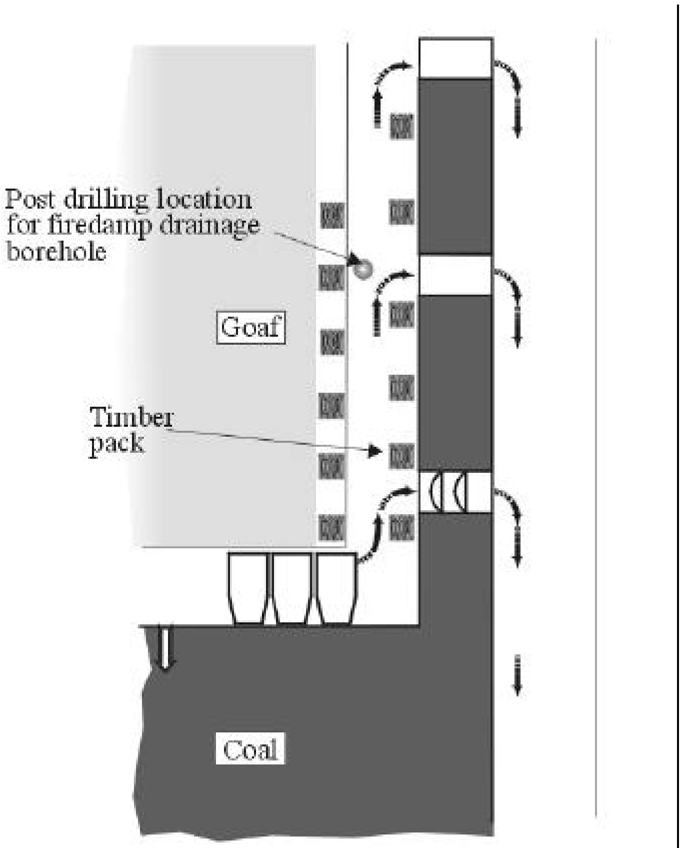

Figure 6 Coal pillar back-return system

Table 8
Prefabricated curtain back-return construction method

Advantages	Disadvantages
• No lost coal • Considered less costly than coal pillar method • Flexible and adaptable • Easily introduced and installed on any retreat longwall district • Condition can be rapidly assessed by visual inspection, and by monitoring the pressure across the curtain at the face end	• Regular supplies of construction materials needed at the coalface • Requires frequent repair to maintain its integrity • Often short-circuited to improve face access allowing firedamp to migrate along the rib side • Position of the “gas fringe” varies with the design and condition of the curtain • Failure to maintain curtain could lead to face stoppages due to gas migration

Table 9
Coal Pillar back-return construction method

Advantages	Disadvantages
• Relatively fail-safe ventilation arrangement • Robust and reliable ventilation of back-return • Needs few additional materials and requires little maintenance in good ground conditions • Significant pressure gradient ensures good goaf edge ventilation resulting in the gas "fringe" generally kept distant from the coalface	• Reduced coal recovery due to abandoned pillars • Construction of cross-cuts. • Reduces district air flow due to the resistance of the cross-cuts • Supplementary support sometimes needed, restricting accessibility and working space • Spontaneous combustion can arise in coal pillars • Restricted face access for materials can lead to production delays

4.2.2 Support systems for borehole stability and access to boreholes

There is a close relationship between strata behaviour, particularly at the return end of a retreat face, and firedamp drainage performance. The design of a district firedamp drainage system must therefore be closely co-ordinated with the specification of face-end strata control arrangements. The benefit of this approach is demonstrated by the case study shown in Box 2.

Box 2
Case study; Improving capture efficiency in a gassy longwall district

Despite ventilation improvements, problems were being experienced on a retreat longwall due to firedamp concentrations in the district return compromising planned coal production. Captures up to 50% were being achieved with the firedamp drainage system. After a detailed assessment the fundamental problem was considered to be roof instability in the vicinity of the boreholes. Factors of possible relevance included:

- The position of the borehole relative to the goaf edge
- The local geology
- The roof support system

Advice was sought from a strata control specialist. Initial evidence suggested borehole failure was due to inadequate strength of packs on the goaf side. Stabilisation of the goaf edge with stronger support possibly complemented by cable bolting in the roof were considered as a remedy. A programme of geotechnical monitoring, including instrumentation of firedamp drainage standpipes was therefore undertaken leading to a re-design of the timber packs. *Linklok* blocks were introduced at the waste edge and hardwood packs used in the gate road.

Capture efficiency was increased from 50% to 60% as a result of improved roof control and borehole stability enabling coal production targets to be achieved.

Safe access to drilling sites and boreholes behind the face, and also the integrity of the drainage boreholes, depends on the effectiveness of the strata support system.

Firedamp drainage boreholes are subject to high stresses when they are close to the face, which if not controlled can cause early failure as shown in Figure 7 and hence poor firedamp drainage performance. An effective support system can stabilise firedamp drainage boreholes as illustrated in Figure 8 and achieve conditions favourable to good firedamp drainage performance.

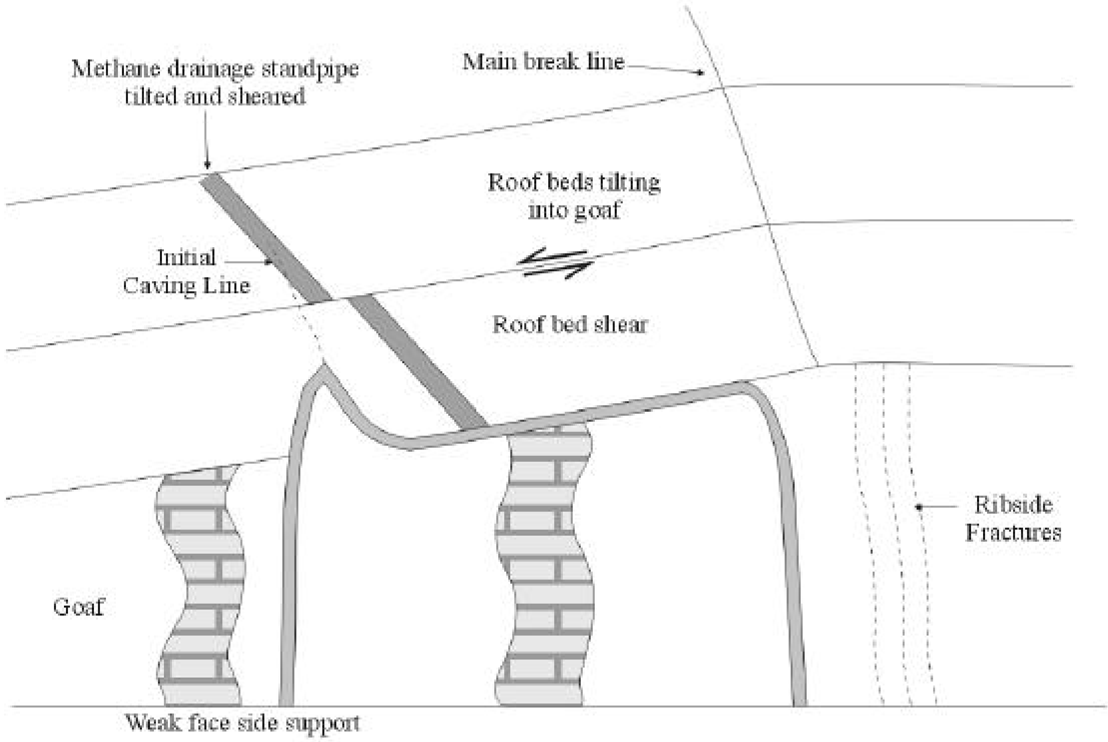

Figure 7 Ineffectively supported borehole

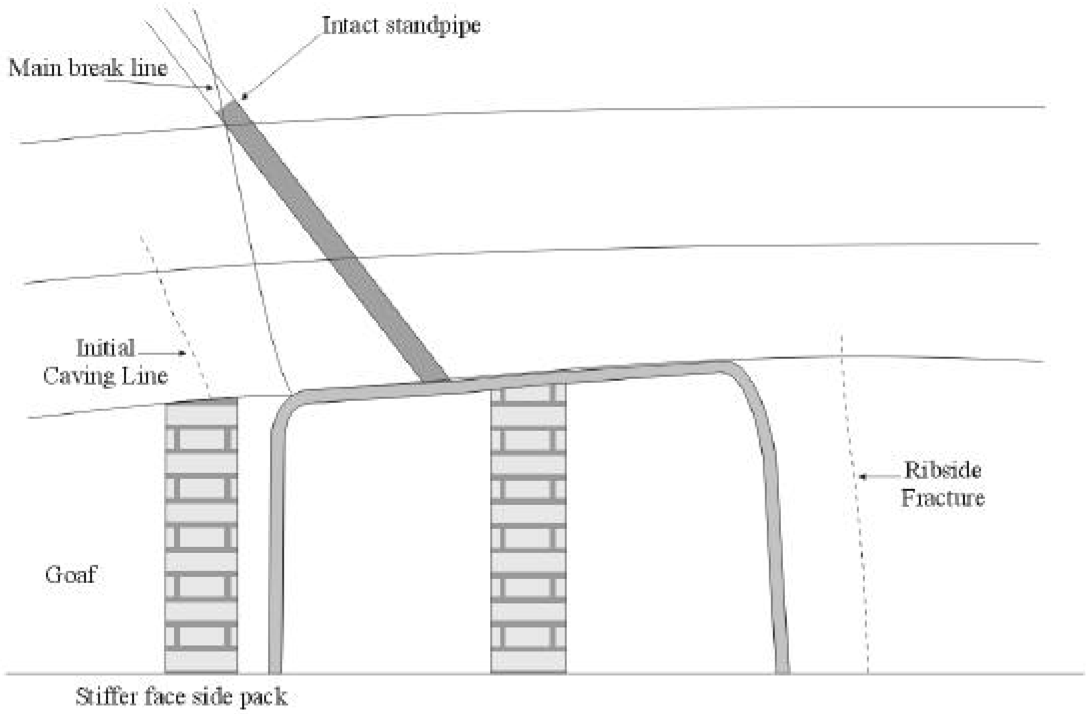

Figure 8 Effectively supported borehole

Grouted standpipes may help to improve roof stability and hence could increase borehole longevity.

The effectiveness of firedamp drainage can be influenced during roadway development, even before the face is started. Early support, especially that achievable using modern roof-bolting techniques, can stabilise the roof and prevent deterioration of gate conditions. Thus conditions are maintained which should be favourable to firedamp drilling and the stability of firedamp drainage boreholes.

Strata control and gas drainage engineers should collaborate closely when designing the face-end support system.

Strain gauges mounted on firedamp drainage standpipes, load cells installed in timber packs and extensometers placed in the roadway can provide data to assist with the design of an effective face-end support system.

Excessive rib movement can lead to crushing of the drainage ranges behind the face against support packs. This is a common cause of loss of drainage capture at a number of collieries. A balance is needed between roof and rib support. Face orientation may also be relevant.

Floor heave can hinder access to the back-return, preventing drilling and limiting the number of boreholes which can be reached for measurement and regulation. The face-end support system should be designed to minimise floor heave.

4.2.3 Firedamp drainage borehole configuration

Borehole design should be determined at the coalface planning stage. Factors to be considered include:

- Differences between the expected performance of roof and floor holes
- Roof and floor drilling locations
- Essential safety precautions
- Standpipe length and method of sealing
- Borehole length, diameter, angle, spacing and target
- Borehole stability

Differences between the performance of roof and floor holes

Roof and floor boreholes tend to perform differently because seams in the roof strata are generally destressed more intensely and rapidly than those in floor strata during mining.

Emissions into floor boreholes therefore may not occur until some time after the face has passed. The percolation of service water and strata water into floor boreholes through breaks in the destressed ground can also suppress gas flows. High gas pressures may be detected in floor boreholes, regular gas flows are less frequently encountered and sustained high capture flows are rare.

In certain geological conditions (Table 2), gas pressures can accumulate in the floor, which if not relieved by drilling floor boreholes, can lead to sudden emissions of large volumes of gas into the roadways.

Where severe floor emissions occur it may be necessary to install a firedamp drainage range and drill floor holes in the intake roadway as well as in the return.

The productive life of a roof hole can commence at 2m and extend from 70 m to 150 m behind the face, although roof holes near the face start line, where the goaf does not fully consolidate, can remain productive for long periods.

Roof and floor borehole drilling locations

Wherever practicable on retreat longwalls, roof holes should be drilled behind the face. The drilling location should be on the goaf side of the back-return to ensure ventilation with relatively fresh, cool face air. When circumstances, such as geological disturbances cause poor roof conditions, drilling can be undertaken on the rib side provided regular tests are made for firedamp layering in addition to continuous monitoring of firedamp concentrations at the drilling machine.

Floor boreholes can be drilled ahead of a retreating coalface with less risk of being damaged by ground movement than roof boreholes, although mining machinery occupying the gate road may make such an operation impracticable.

Essential safety precautions

Roof and floor boreholes should always be drilled through a ‘stuffing box’ to control any high pressure gas or water unexpectedly encountered during drilling. The ‘stuffing box’ should be attached to a secure standpipe.

Standpipe length and method of sealing

The immediate roof and floor strata of the workings are invariably intensely fractured by mining to distances of around 10m in the roof and about 5m in the floor. Attempts to drain firedamp from any seams within these zones are likely to lead to a high air inflow, and hence low gas purity, and loss of suction. Coal seams beyond these zones are potential targets for drainage capture and standpipe lengths should be selected accordingly. A solid standpipe should, therefore, be installed to pass through the fractured zone.

The length of standpipe in a roof hole should be designed to terminate near the break line at the goaf edge (see Figure 8). Roof standpipe lengths are likely to be 15m or greater to ensure contact with reasonable purity gas with low air contamination. The minimum standpipe length for a floor hole should be 5m.

The standpipe diameter should allow the drill bit to pass through to enable the productive length to be completed (eg. 75mm diameter standpipe, 50mm diameter borehole).

Standpipes are traditionally sealed in place with a ‘Densotape’ plug against which drill chippings accumulate. The use of resins and grouts should be considered where ineffective seals are formed (air drawn into the pipe dilutes the captured firedamp to a low purity) or where high gas pressures are expected, for example, when drilling into the workings of an adjacent mine that has been abandoned.

Borehole length

Gas capture is generally not improved significantly by extending the lengths of roof holes more than 50 m above the working horizon unless there is a major coal seam a few metres beyond this distance.

Where practicable, gas drainage boreholes should be drilled to a target coal seam as:

- The distance of the target seam may vary and drill returns confirm attainment of the target seam (and hence the borehole is of the correct length)
- An opportunity to capture gas at source

Floor boreholes are drilled to intersect floor seams that lie within the destressed zone. They are likely to be the most productive where seams lie at, or within, 20 m of the worked seam.

Sudden emissions of gas can occur from floor strata when a strong bed in the floor, overlying one or more coal seams, resists breaking until the stresses accumulate and the bed fractures. Gas released from the seams below flows rapidly into the mine. Where this geological configuration has been identified, floor holes should be designed to penetrate both the strong bed and the underlying seam to mitigate the sudden emission risk.

Borehole diameter

The total gas mixture flow in a firedamp drainage borehole depends on the suction pressure, gas pressure, resistance of the strata and resistance of the borehole. Borehole diameter will only be a limiting factor if the gas is capable of entering the borehole at a rate which exceeds its capacity.

Increasing the diameter of boreholes can lead to an increase in gas flow if the major gas sources are close to the ends of the holes and the resistance to flow in the borehole limits the available suction at the productive horizon.

However, an increase in diameter is likely to increase the installation time per hole and may constrain borehole spacing

Borehole angle

Boreholes drilled from the waste side of the back-return are typically angled at 60 degrees and should always be drilled normal to the gate-road. Angles may need to be reduced when drilling from the rib side, or when drilling across coal pillars, to obtain a similar interception of a coal target above the goaf.

Angled boreholes which do not cross the goaf edge are unlikely to yield significant gas flows.

Borehole angles may need to be adjusted where strong beds in the immediate roof strata delay full caving of the goaf.

Borehole spacing

Optimum spacing of roof boreholes is attained when the required drainage capture is consistently obtained with the minimum interference between boreholes. Interference should be tested by measuring closed borehole pressures. This is achieved by closing the valve where the flexible hose is joined to the range of each borehole in turn, leaving the other boreholes on suction and measuring the pressure of the closed borehole. A negative pressure indicates suction is being transmitted through strata breaks from an adjoining hole. However, care must be taken when interpreting the results as a badly seating valve will give a false indication.

If a floor emission risk has been identified, a floor hole should be drilled and connected to the drainage range within a specified distance of the face determined from experience of the particular seam being worked. These floor boreholes may not yield significant gas flows, but they provide an essential pressure relief mechanism.

Borehole stability

Standpipe and borehole shearing due to ineffective roof control can lead to loss of gas purity and reduced drainage capture efficiency.

Perforated or slotted pipe can be attached to the solid standpipe section to keep the productive borehole length open and reduce the likelihood of premature failure. However, this approach may not be successful where the fundamental cause is an inadequate support system. In such instances managers are advised to seek specialist assistance.

4.2.4 Infrastructure

The firedamp drainage infrastructure consists of the ranges leading from the face to the collection pipework in the main colliery access roads and ultimately to the extraction pumps. The design and performance requirements of the firedamp drainage infrastructure should be determined on the basis of the total flows of gas that are likely to be drained from all sources including working longwalls, salvage districts and sealed areas of the mine.

The capability of the firedamp drainage pipework to transmit the gas depends on:

- The flow capacity of the system
- Integrity of the pipework
- Effectiveness of dewatering systems

A visual representation of the firedamp drainage system is an essential aid to the design of infrastructure.

A firedamp drainage plan of the mine should be prepared showing the locations of:

- All installed firedamp drainage ranges (pipe diameters indicated)
- Fixed monitors
- Orifice sets (size to be indicated)
- Tappings (for suction pressure measurements)
- Control valves (with reference numbers that are also clearly displayed underground) and a symbol indicating the current valve setting (fully open, partially open, closed)
- All workings, salvage and abandoned districts connected to the system

The plan should be reviewed annually or following any major revision, or extension, of the firedamp drainage system.

A schematic plan of the firedamp drainage plant should also be prepared and a copy clearly displayed in the methane plant. The schematic plan should show:

- Arrangements of pumps and pipework
- Directions of gas flow
- Monitoring locations
- Orifice plate sizes
- Control valves
- Composite pump curves and usual operating point

Flow capacity

The flow capacity of the system depends on the number and size of pumps in the methane drainage plant and the transmissibility of the pipework system from the face to the methane plant.

The firedamp drainage pipework should be capable of accommodating the maximum expected captured gas mixture (methane and air) flows. The highest firedamp flows likely to be encountered when working faces in virgin areas when none of the gas in adjacent strata will have been removed by previous working of seams above or below.

To obtain the worst case mixture flow (ie., the highest flow that has to be transported) combine the highest expected captured firedamp flow with the lowest gas purity expected to arise during normal operations. The resulting flow should be within the planned capacity of the system when all the pumps are operating. An assumed worst case (low) gas purity of less than 35% should be considered unacceptable.

The pipework and pump combination should be capable of providing 5kPa of suction, or more, at drainage boreholes on producing longwalls.

The capacity of the pipework is increased by installing additional parallel ranges, replacing existing pipe with larger diameter pipe or re-routing pipework to shorten the transmission distance. The former is usually the most effective approach and should be used provided there is sufficient space in the roadways to accommodate the new pipework.

Drainage infrastructure for production districts

In addition to the flow and suction factors mentioned above, the number and diameters of ranges to be installed in a longwall district should also be determined from consideration of the:

- Borehole connection strategy
- Floor emission risks

At least two ranges in parallel should be installed on gassy retreat faces to provide a means of controlling gas purity and maintaining suction. As new boreholes are attached to a range, the increasing total gas flow results in a decrease in suction. At the same time, the gas purity in older holes may begin to decrease. The number of boreholes that can be successively linked (likely to be from 4 to 6) to a specific district range without detriment to the designed capture can thus be determined. Subsequently, batches of holes should be linked to each range in turn.

Expanding regulators can be inserted in ranges inbye of the last active batch of holes to reduce the inflow of low purity gas from older damaged holes or from pipework that has been damaged by ground movement. An alternative approach, if gas purity is declining, is to cut the range that is not in use, blank off the exposed ends and connect the inbye section to a third “sewer” range. These various methods are illustrated in Figure 9.

Gas in floor seams can be difficult to capture due to water entering the holes and being produced along with the gas. The risk of the range becoming waterlogged can be reduced by connecting floor holes to a separate range than the roof holes.

Where gas emissions are low and the need for firedamp drainage is marginal, then at the discretion of the manager, a single range can be installed. In mines with a history of major floor emissions, firedamp drainage may also be needed in the intake gate. A single range may suffice in such instances.

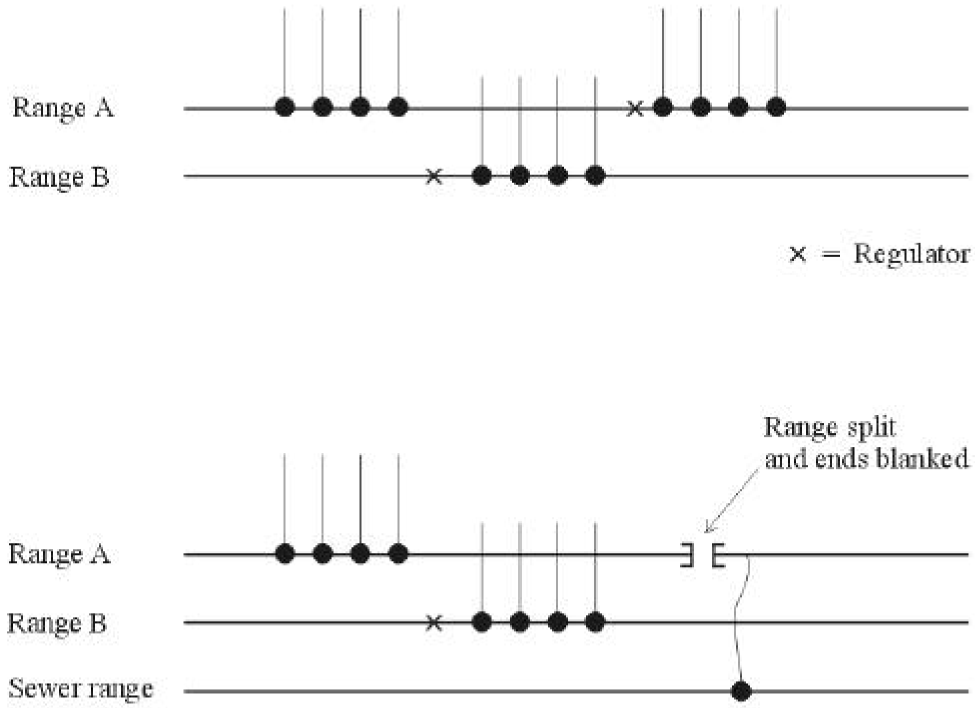

Figure 9 Batch control of boreholes using multiple ranges

Integrity of the pipework

Consideration should be given to the use of suitable materials for different parts of the drainage pipework infrastructure. Steel or GRP firedamp drainage pipe is available. The advantages and disadvantages of these materials are compared in Table 10. GRP ranges are relatively brittle and should not be used in coal production districts. However, ease of handling and installation, compared with steel pipe, makes them the preferred material for the main ranges. Where space is restricted and the range might be vulnerable to physical damage (eg., from roadway deformation or free-steered vehicles) steel pipe should be used.

The need to incorporate expansion joints to accommodate movement should be considered when designing shaft ranges and pipe runs in long roadways.

Dewatering systems

Firedamp drainage ranges should be installed on a gradient to allow water drainage via water traps at low points. Manual drains need to be checked daily until a trend is obtained and a suitable schedule established. If persistent water problems are expected consideration should be given to the installation of automatic dewatering systems.

Table 10
Comparison of drainage range materials

GRP		Steel	
Advantages	Disadvantages	Advantages	Disadvantages
• Ease and safety of: handling • Small team • Rapid installation • Lower internal friction co-efficient than steel • Does not corrode • Easily salvaged	• Vulnerable to damage from traffic • Higher cost than steel • Sharp bends and junctions need to be pre-formed by manufacturer • Not always readily available from suppliers • Not suitable for use in working districts	• Strong and resistant to accidental damage • Lower cost than GRP • Bends and junctions can be fabricated at the mine • Suitable for all parts of the mine • Can be drilled and tapped in situ to accept valves	• Heavy to transport and handle • Labour intensive to install • Greater risk of injury; • Slower to install than GRP • Internal friction may increase with age due to corrosion

4.2.5 Installation and commissioning

The installation and commissioning procedures put in place should ensure that the system is installed and operated to the design specification.

Precautions to be adopted when installing and commissioning drainage pipework are summarised in Table 11.

Table 11
Installation and commissioning pipework

- Protect ends from accidental damage during transport and handling
- Visually check pipes are free of internal debris before installing
- Check GRP pipes are free of release paper before installing
- Ensure secure lifting arrangements
- Align pipework within limits of joint
- Check collars and seals are clean and serviceable when joining pipes
- Support securely with chain, clear of traffic
- Position, support and protect district ranges to minimise vulnerability to damage when behind the longwall retreat face
- Check all joints are air-tight (air in-leakage can be heard when suction is applied). Rectify persistent minor leaks with sealants. Replace joints and re-align pipework where major leaks are found
- Install de-watering equipment where pipework dips and there is evidence of water accumulation

Maintenance

All equipment in the firedamp drainage system, together with firedamp drilling equipment should be included in the manager’s planned preventative maintenance scheme.

Firedamp drainage valves should be regularly inspected and maintained, including those that are used infrequently. Valves should be clearly marked with a number corresponding to a reference on a firedamp drainage plan.

Firedamp drainage ranges should be regularly inspected. Leaking joints (detected by sound) should be repaired, and pipes re-aligned if necessary. Missing or damaged suspension chains should be replaced.

4.2.6 Monitoring

Mining legislation sets precautions to be adopted in the design, selection of equipment and operation of firedamp drainage and utilisation plant at mines.

The method, type and frequency of monitoring together with the format of presenting information should be considered for the whole of the firedamp drainage system.

In designing a monitoring scheme, consideration should be given to the following:

- Monitoring techniques
- Types of measurement
- Presentation of information
- Use of the monitoring information

Monitoring techniques

Monitoring techniques using manual and remote systems (Table 12) should be used to confirm the effectiveness of the firedamp drainage system. The quality of this monitoring depends on the reliability of sensors, their positioning, maintenance, calibration and use.

Types of measurement

Measurements are needed at boreholes, in ranges and at the methane plant of mixture flow, gas concentration and pressure. The details of any monitoring scheme, and methods adopted, will be colliery specific. Table 13 shows the type of measurements that are likely to be needed, where they should be measured and how often.

Table 12
Monitoring options

Method	Advantages	Disadvantages
Manual	• Only collect data when required • Allows for visual inspection of conditions • Easy to respond to emergency need for additional monitoring • Flexibility in sampling and analysis	• Time taken for person to visit site and obtain measurement • Monitoring tends to be patchy and trends may be difficult to determine from records • Potential for human error in sampling and measurement • Data may not be easily readable or accessible when kept in personal notebooks • Calibration and maintenance of different types of instrument
Remote	• Continuous data • Simultaneous monitoring of several variables • Sampling frequency easily changed • Automatic alarm facility • Information immediately available to management • Historical data available for analysis whenever required • Can be linked control system	• Can be costly to install, maintain and calibrate • Large quantities of data to process • Transducers may deteriorate after prolonged exposure in the underground environment • Only usable where power supply permitted • Monitoring locations fixed • Standby batteries required to facilitate monitoring during a power trip or outage

Pressures and gas concentrations are measured directly using calibrated equipment. However, flow is measured indirectly from a determination of the pressure drop across a circular restriction or orifice plate in the pipe. The orifice plate is a precision instrument and must be installed correctly in the pipe as shown in Figure 10, and its dimensions must be known. To prevent incorrect values being used in calculations, all orifice plates should be clearly marked showing orientation and orifice diameter.

Flow rate should be computed using a circular firedamp flow calculator, or proprietary computer program and corrected to standard conditions of pressure and temperature after making allowance for the gas composition.

Monitoring individual borehole performance is essential as it will provide the information needed to manage the drainage system and to further the development of the drilling strategy for the face unit. It will also indicate if changes are required in response to changing geological and production requirements.

Table 13
Firedamp drainage monitoring scheme

Gas control	Monitoring	Frequency	Location
Drainage borehole	Gas purity, mixture flow, suction pressure and closed borehole pressure	Daily	Monitoring of accessible boreholes behind the face line
District drainage ranges	Gas purity, suction pressure and flow	Daily/weekly	Monitoring at the outbye end of the district. Remote monitoring equipment linked to the surface can be used. Manual checks should be made at least weekly to confirm readings
	Water traps	Depends on accumulation rate	All installed water traps. Note the quantity of water drained and amend draining frequency accordingly. Traps in intake airways will collect condensation
Outbye methane drainage pipe network	Gas purity, suction pressure and flow	Weekly	Gas inputs into the drainage range from all working, salvage and sealed districts
	Water traps	Depends on accumulation rate	All installed water traps. Record the quantity of water drained and amend draining frequency accordingly. Traps in intake airways will collect condensation
Surface firedamp extraction plant	Gas purity, suction and flow	Daily	The firedamp extraction plant. Individual pumps tested on a six monthly basis

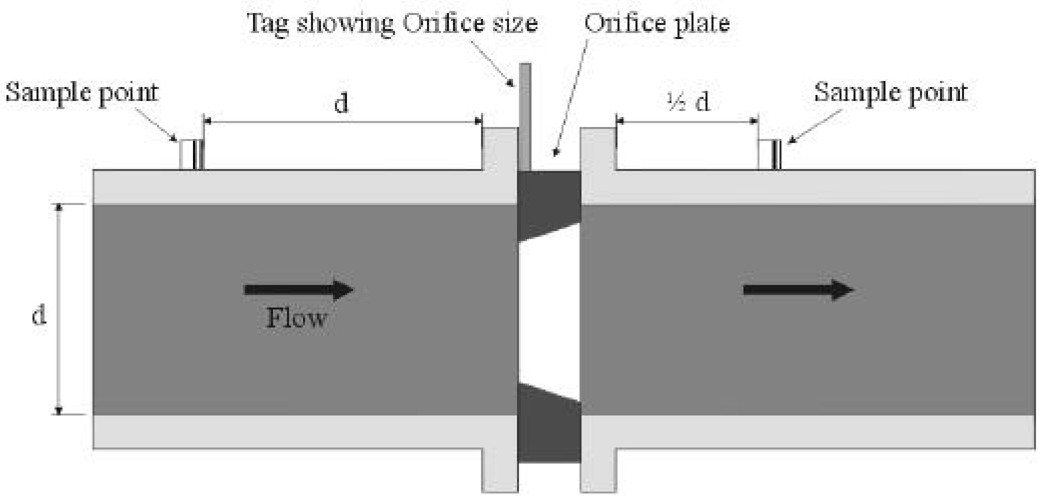

Figure 10 Measurement of fire-damp drainage flow

Table 14 shows the type of measurements that should be made on drainage holes and how to make them.

Table 14
Measurements on firedamp drainage boreholes

Gas flow	A measuring set (usually 50mm diameter) incorporating an orifice plate and sample tappings is installed between the borehole and drainage column
Purity at the borehole mouth	A single sample tap will enable gas to be drawn into a bladder then discharged through a high reading methanometer to determine the firedamp concentration. A low value implies excessive air is being drawn into the borehole
Purity within the borehole	Push a sampling tube into a borehole under suction using drain rods inserted through a gland. Connect the tube to the range to ensure a steady gas flow. At different positions in the borehole, sample the gas from a T-piece in the tube using a Gresham pump
Closed borehole pressure	Closed borehole pressure is measured at the borehole tapping with a magnahelic after closing the valve on the connection to the range. A positive pressure may indicate insufficient suction. A negative pressure demonstrates borehole interaction but care must be taken not to misinterpret due to a leaking isolation valve
Intact borehole length	Determined by pushing rods into the hole until an obstruction is met which cannot be forcibly removed. Sometime boreholes with low purity are found to have sheared within the standpipe length. Strengthened casing is not always successful in alleviating the problem which is invariably indicative of an inadequate roof support system around the boreholes

Presentation of information

Information should be presented in a format that clearly identifies the performance of the methane drainage system, where trigger or action values have been exceeded. Reporting of monitoring results can take various forms from daily record sheets to detailed assessments and annual reviews.

In addition to meeting legal requirements, monitoring provides essential management information on the effectiveness and efficiency of the firedamp drainage system. Ventilation, gas and firedamp drainage data of the type shown in Table 15 should be presented on a pro forma which clearly shows the current gas control performance and highlights any potential problems which require attention.

Key output provided by remote monitoring systems should be available on displays to relevant managers and those responsible for firedamp-related functions.

Table 15
Essential management information

Each working district
The following firedamp drainage data should be summarised weekly on a simple pro forma and issued to line management on a weekly basis: • Target captured gas flow (pure) • Actual captured gas flow (pure) • Target firedamp drainage efficiency (%) • Actual firedamp drainage efficiency (%) • Borehole spacing and angle (roof) • Borehole spacing and angle (floor) • Intake firedamp pollution (%) • Outbye return firedamp concentration (%) • Drilling location and conditions • Any problems with the firedamp drainage • Actions required and by whom
Colliery (weekly)
• Pure firedamp flow and purities at each working district • Pure firedamp flow and purities from old districts • Total pure firedamp flow, average purity and vacuum at the methane plant

Use of the monitoring information

Monitoring should be used to assess the actual performance of the installed system against the original design concept. Table 16 shows how monitoring results from firedamp drainage holes can be interpreted and their performances improved.

Table 16
Improving firedamp drainage borehole performance

Suction	Purity	Possible cause	Action
Low	Low	Inadequately sealed standpipe	Improve sealing method. Review standpipe length. Repair
Low	High	Drainage range disconnected or severed	Check status of pumps and pipework. Review the firedamp drainage capacity
High	High	Outbye pipe capacity too low, too few extraction pumps or outbye blockage in the district range	Review geology and drilling pattern
High	Low	Coal seam target which may not have been disturbed by mining. No contact with a gas source, or gas source depleted	As above

Practical gas drainage problems in collieries can generally be resolved by the application of existing knowledge and techniques. Innovation and novel technologies can be considered but only after good practice application of existing techniques has been tried.

Printed and published by the Health and Safety Executive
C1 03/01

HSE
BOOKS

MAIL ORDER
HSE priced and free
publications are
available from:
HSE Books
PO Box 1999
Sudbury
Suffolk CO10 2WA
Tel: 01787 881165
Fax: 01787 313995
Website: www.hsebooks.co.uk

RETAIL
HSE priced publications
are available from
good booksellers

HEALTH AND SAFETY ENQUIRIES
HSE InfoLine
Tel: 08701 545500
or write to:
HSE Information Centre
Broad Lane
Sheffield S3 7HQ
Website: www.hse.gov.uk

CRR 326

£15.00

ISBN 0-7176-1967-2

9 780717 619672