8 Methane

To inquire into . . .

(c) whether any neglect caused or contributed to the occurrence;

(f) whether there was compliance with applicable statutes, regulations, orders, rules, or directions

The introduction of methane to mine air is a natural consequence of coal mining. The flammability of methane is not the only hazard it poses to underground coal mine workers. Although methane is a non-toxic gas, if present in sufficient concentration it will depress the oxygen content of the air. A lack of oxygen will produce the physiological effects outlined in table 8.1.

Methane burns in air with a pale blue flame. If a stream of high-concentration methane is emitted into the air and ignited immediately, it will burn in a controlled manner, as natural gas or propane does in the flame of a gas stove's burner. The appearance of a pale blue halo of burning methane immediately above the lowered flame of an oil lamp has provided a means of measuring methane concentrations in mine atmospheres since the early 19th century. This is the principle behind the locked flame safety lamp. Although mostly superseded by the hand-held methanometer, the flame safety lamp is still recognized as a legitimate testing device by section 72(1) of the *Coal Mines Regulation Act.* Section 82 deals with the care and use of the lamp.[1]

If the gas is well mixed into the air *before* an igniting source is applied, the reaction can be very different, depending on the concentration of methane in the mixture. At a concentration of less than 5 per cent, methane will burn only at the points of contact with a surface that is maintained at a sufficiently high temperature. The flame will neither leave that surface nor propagate through the mixture. At a concentration of between 5 and about 15 per cent methane (the latter depending on the proportions of oxygen and other gases present), flame will propagate spontaneously throughout the mixture. At concentrations above 15 per cent, there will be insufficient oxygen to maintain the combustion unless an artificial supply of oxygen has been added to the atmosphere. The speed of the flame increases as the concentration rises above 5 per cent and reaches a maximum at 9.6 to 9.8 per cent. At that level, the gas is at its most explosive. Then, as the methane concentration continues to rise, the flame speed will decrease, the flame being extinguished completely at 15 per cent.

If the combustion takes place in a plentiful supply of air, the methane and oxygen will form carbon dioxide and water vapour. However, if there is insufficient oxygen for complete combustion, the highly toxic carbon monoxide will be formed.

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[1] Methane detection devices are discussed in greater detail in the section on detection and monitoring later in this chapter.

Table 8.1 Physiological Effects of Oxygen Deficiency

Oxygen in Air (%)	Effects
20.9	Normal concentration in fresh air – no adverse effects
17	Noticeable increase in rate and depth of breathing – an effect further enhanced by an increased concentration of carbon dioxide
15	Dizziness, increased heartbeat
13–9	Disorientation, fainting, nausea, headache, blue lips, coma
7	Coma, convulsions, and probable death
Below 6	Death

Source: Malcolm J. McPherson, *Subsurface Ventilation and Environmental Engineering* (London: Chapman & Hall, 1993), 375.

Because the total amount of oxygen available for combustion in an enclosed underground space is limited, it stands to reason that, in the case of a fire or an explosion, oxygen will be consumed very quickly. Throughout the long history of fires and explosions in coal mines, the majority of fatalities have occurred as a result of carbon monoxide poisoning, not from burning or blast effects.[2]

Methane in Coal

Methane is a normal bacterial and chemical product of the decay of vegetation. The thick organic sediments that produced peat and (ultimately) coal were a prolific source of this gas. Over millions of years, the metamorphic effects of strata pressure and temperature gradually converted that original vegetation into the black rock we know as coal. Coal is a porous substance. The pores, although numerous, are not visible to the naked eye. Within these exceedingly small pores the methane now resides. Through a process called adsorption, coal can hold far greater quantities of methane than can non-adsorbing rocks.[3]

For gas to be released from coal, there have to be flow paths big enough to accommodate the gas molecules and there must be a region of lower pressure towards which the gas can flow. As mine workings advance into virgin coal, natural fracture planes will open up and new fractures will appear. Meanwhile, the barometric pressure in the workings will be much lower than the pressure in the coal. Methane will therefore migrate from the pores in the surrounding coal towards mine openings.

[2] As we have seen in Chapter 6, The Explosion, 10 of the 11 miners who died in the Southwest section succumbed to carbon monoxide (medical examiner's report, Exhibit 44.0077).

[3] The subject of gas adsorption is covered in detail by Dr Malcolm J. McPherson in his book *Subsurface Ventilation and Environmental Engineering* (London: Chapman & Hall, 1993), chapter 12.

Methane Release into Mine Openings

At a working face in a coal mine, methane is released from two main sources. First, methane will emanate from all exposed coal surfaces – rib, roof, floor coal, and the coal face itself. The rate of emission is greatest when the coal surface is first exposed. It then will decrease over time, although the gas flow can continue for long periods. (The rate of decrease depends mainly on the permeability of the surrounding coal strata.) Gas emission from standing faces or ribs can often be heard as a hissing sound, particularly if the surface is wet, and it is not uncommon to observe bubbles of methane emerging from floor sources through standing water. Ray Savidge, a one-time Westray mine surveyor, observed this phenomenon while the main slopes were being driven, stating that "there was water at the face and there was evidence of gas because it was bubbling . . . like a hot spring."[4]

The second main source of gas is at the points of fragmentation in the coal as it is mined from the working face. The rate of gas emission here depends not only on the gas content of the coal, but also on the degree of fragmentation. The gas emission rate at the pick points of a coal mining machine increases as the average size of coal particle decreases. Hence, the use of dull picks, which produce greater amounts of dust, will also result in enhanced gas emission.

In addition to those two primary sources of gas at a working face, other, secondary sources exist. The fragmented coal will continue to emit gas while being transported from the mine. Gas may also come from source seams within the overlying and underlying strata. This occurrence is more probable in longwall systems of mining, which experience greater movements of roof and floor strata.

Methane will continue to emanate within abandoned sections of a coal mine. In most cases, the rate of emission will reduce over time as a result of degassing of the surrounding strata. However, as long as active ground movement continues to crush coal-bearing strata, higher methane emission rates will persist in the abandoned area.

Less common causes of emission are found as well. In heavily faulted regions, pockets of pulverized coal may exist within the seam. These can give rise to outbursts – sudden large emissions of methane, accompanied by an outpouring of dust. Other types of outbursts can occur from localized gas reservoirs in roof or floor strata. If the relaxation of the strata caused by mining results in fractures connecting to large sources of methane, the gas flow can remain at a high level for long periods. In such circumstances, that methane may be commercially viable or provide a source of low-cost energy for local use. Tapping into a fracture network for controlled drainage of methane was suggested for Westray as late as 1991.[5]

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4 Hearing transcript, vol. 22, p. 4335.

5 In a letter to Gerald Phillips dated 14 November 1991, Jeff Schwoebel of Resource Enterprises, Inc., notes the potential for commercial methane recovery from Westray's properties (Exhibit 36c.1). Resource Enterprises was at this time associated with G.P. Isenor

Effects of Barometric Pressure

As a result of short-term variations in local climate, the barometric pressure at the surface of the earth is seldom absolutely constant. In changeable weather, the barometric pressure can alter quite quickly. Such changes are reflected in similar variations occurring throughout the active ventilation system of a mine. Although the effect on the methane emitted from undisturbed solid coal is negligible, the situation is different for gas that has already escaped from the coal and has accumulated in unventilated spaces – including old mine workings that are no longer ventilated. Such was the case in the Southwest 1 section after mining abruptly ceased there following the severe ground control problem in early 1992.

Figure 8.1(a) illustrates a situation in which the barometric pressure in the active ventilation system of a mine is rising. As normally constructed, seals and stoppings in underground mines are not leakproof.[6] Whenever a difference in air pressure exists across a seal, some degree of leakage will occur through or around it. During a transient period when the air pressure outside the seal is greater than that within the old workings, air will leak inward, compressing the mixture of gases that exists there. Figure 8.1(b) shows the opposite effect: a falling barometric pressure will result in expansion of gases in the sealed area, causing some of them to leak outward into the active ventilation system of the mine. The latter effect is the more hazardous with respect to contamination of airflows supplied to working areas. Such outflows of gas resulting from a falling barometric pressure are *additional* to the emissions of gas that continue to occur from the strata in those same abandoned areas.

As the barometric pressure rises and falls according to the weather patterns on the surface, seals can be said to "breathe" inward and outward. The phenomenon results in a mixing of air and methane within a zone inbye the seal. As a consequence, a potentially explosive mixture could form there. The danger from falling barometric pressure is what underlies the requirement to maintain a barometer on the surface of the mine.[7] As well, the outward leakage from old workings requires that intake airways avoid entrances to old workings or other places where the air is likely to be contaminated.[8]

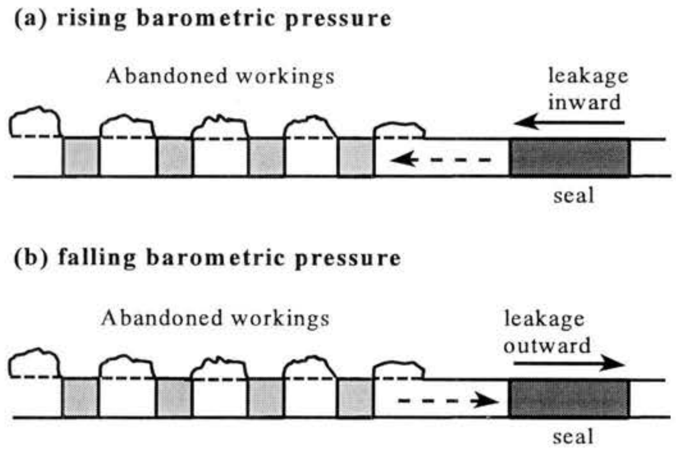
Company Limited of Bedford, Nova Scotia. GPI had recently completed its Coalbed Methane Report, Atlantic Canada, for Petro-Canada Resources (Exhibit 36c.1, s. 5b).

6 "Normally constructed" refers to permanent stoppings comprising double concrete-block walls filled with non-combustible waste material. It does *not* describe the makeshift plywood and plastic structures erected at the openings to Westray's Southwest 1 section.

7 The *Coal Mines Regulation Act*, RSNS 1989, c. 73, requires that a barometer be kept at the surface of an underground coal mine (s. 92(1)) and that underground managers and examiners take regular readings (ss. 36(2), 38(4)). Roger Parry, underground manager at Westray, chose to ignore the importance of both the barometer and the water gauge. Besides placing himself in violation of the act, he showed an appalling lack of common sense or good safety judgement.

8 Section 71(6) of the *Coal Mines Regulation Act* states that "[a]ll intake air shall travel free from all . . . old workings and other places likely to contaminate the air."

Figure 8.1 Seals Can "Breathe" with External Barometric Pressure Change



Source: Prepared by Malcolm J. McPherson for the Westray Mine Public Inquiry.

The Behaviour of Methane in Air

Buoyancy Effects and Methane Layers

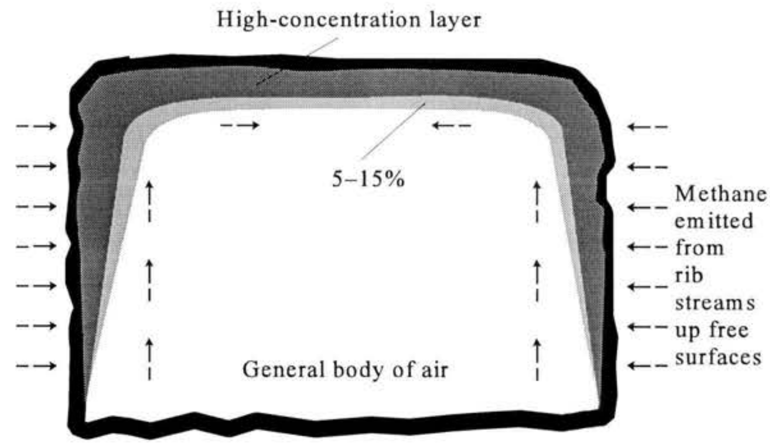
When methane is emitted from the coal or other strata, it is highly concentrated – perhaps in excess of 95 per cent purity. If that gas is to be removed from the mine via the ventilation system, it must be diluted to a safe concentration. It follows that, between the points of emission and the general body airflow, the gas must pass through the flammable range of 5 to 15 per cent. It is important that the space occupied by the flammable mixture be minimized and that the mixing process take place as quickly as possible.

The buoyancy of methane gives it a tendency to move upward and accumulate at roof level, but only while the gas remains at a relatively high concentration. If the gas becomes mixed with the air, the mixture will be homogeneous and there can be no upward streaming. Once mixed with the air, the methane cannot separate out again. Figure 8.2 illustrates the vertical surfaces of coal ribs in an entry with a low air velocity. Methane issues at a high concentration from one or, more usually, many points of emission. The gas immediately streams upward because it is much lighter than the adjacent air. Furthermore, it tends to adhere to the surface rather than pass outward into the air. A similar pattern occurs at a coal face or any other surface emitting methane.

If the velocity of the air is sufficiently high, turbulent eddies will promote good mixing close to the points of emission; neither the vertical streams nor a roof layer of methane will form.

If a methane layer is allowed to form, its behaviour in the airway will be influenced mainly by the velocity of the air under the layer and the

Figure 8.2 Methane Layer Formation



Source: Prepared by Malcolm J. McPherson for the Westray Mine Public Inquiry

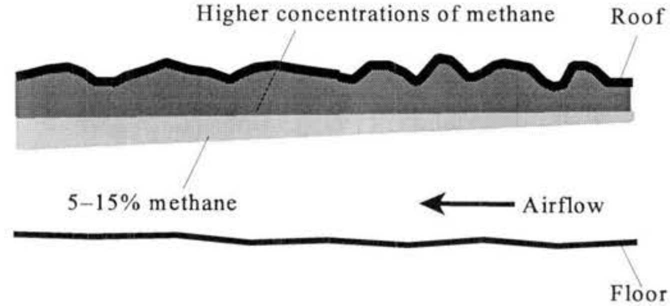
inclination of the airway. If the air is completely stagnant in a level entry, a methane layer will spread along the roof of the entry in both directions. If the air is moving, the lower portion of the layer will be dragged along in the same direction. The upper regions in the layer are similarly induced to move at progressively lower velocities until the gas actually at roof level may be nearly stationary. The eddying interactions between the methane and the underlying air help to promote movement of the layer while at the same time producing a mixing action. The result is that the lower regions of the layer become more dilute and the zone that contains a flammable methane-air mixture increases in thickness (see figure 8.3).

In an inclined entry with no movement of the air, the methane layer flows upward because of its buoyancy. If the air is also flowing upward, the buoyancy and drag forces act together to promote further motion of the gas, lengthening the layer. If the airflow is downward, the buoyancy and drag forces act in opposition, in which case the methane layer tends to move according to the more dominant force or even spread in both directions. The greater relative velocity between the air and a methane layer in downward-ventilated entries causes a greater degree of turbulent mixing.

Methane layers pose a number of dangers:

- They are a means by which methane can propagate along mine entries without rapid mixing, thus remaining at a high concentration.
- The volumes and concentrations of methane in a layer may be sufficient to result in an explosive mixture within the general body if dissipated by increased turbulence or a shock wave.

Figure 8.3 Airflow Induces a Methane Layer to Flow and Thicken



Source: Prepared by Malcolm J. McPherson for the Westray Mine Public Inquiry

- The underside of a concentrated layer provides a continuous path along which a flame can propagate should the methane be ignited at any point.[9]
- If a flame reaches a zone where the 5 to 15 per cent band has thickened significantly, the speed of the flame may accelerate to explosive velocities and produce a shock wave. This shock wave in turn can lead to a coal dust explosion.
- Methane layers may connect into roof cavities, old workings, or other areas where large accumulations of gas may exist.
- Personnel working near roof level may suffer from oxygen deprivation in the presence of a thick methane layer.

At Westray, many entries had uneven roofs because of cavities resulting from roof falls and overbreak. Numerous cavities existed above the tops of steel girders or arches that had been installed to support the roof. The cavities were essentially unventilated and would fill up with gas if they lay in the path of a methane layer. Even in the absence of such a layer, emissions from roof or rib sources may have caused local accumulations of the gas in roof pockets.

Methane layers can be detected only by testing for the gas at roof level. Methanometer extension accessories facilitate the procedure in mines working thick seams. These were not used routinely at Westray, although at least one methanometer extension unit was available in April 1992.[10]

Methane Emissions at Mining Machines

The combination of freshly exposed surfaces of coal and the breaking up of material into small fragments by mechanized equipment can cause the working face to become a prolific producer of gas. On the type of

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9 This point supports the "rolling flame" postulated by Reg Brookes in his hypothesis for the explosion (see Chapter 6, The Explosion).

10 Trevor Eagles testified that he found a methanometer extension and used it for a few weeks (Hearing transcript, vol. 76, pp. 16618–19).

continuous miner used at Westray, a cutting drum with tungsten-carbide–tipped picks rotates on a horizontal axis (see photo 2 in Reference). The machine is moved forward to begin cutting – at either roof or floor level – into one-half the face width. The drum is then moved down or up, cutting and removing the coal to the required height. Three machine-mounted mechanisms help to dilute and remove methane from the vicinity of the cutting drum.

First, the rotation of the drum creates air movement. The direction and magnitude of the air motion depends on the design of the cutting drum and its rotation speed. Second, the water sprays directed at the drum for dust suppression induce a movement of air. The third and perhaps most effective mechanism is the dust extraction system. A mixture of air, dust particles, and gas drawn into openings at the front of the body of the continuous miner – immediately behind the cutting drum – passes along an internal duct system and through a water-assisted dust filter before being ejected towards the rear of the equipment. It appears that the dust extraction system on the continuous miner in the SW2-1 heading was not operating at the time of the explosion.[11]

These mechanisms have little influence on the methane emitted from exposed coal surfaces other than the one that is actually being mined. Methane emerging from the ribs and the block of coal on the other side of the face (the side not being cut) is affected very little by the machine-mounted devices. Furthermore, unless the auxiliary ventilation system for the heading provides both a sufficient quantity of air for dilution and the velocity necessary for efficient mixing at the head end, uncontrolled recirculation in that zone may result in the build-up of unacceptable methane concentrations.

Methane Emissions in the Westray Mine

Predicted Gas Emissions at Westray

In 1980, Algas Resources Ltd carried out a detailed investigation of the methane content of coal seams in the Pictou County coalfield, including the Foord seam, the seam that Westray would later attempt to mine. Known as the Nova Scotia Demethanation Project, the investigation was intended to provide data on the feasibility of extracting methane via surface boreholes for sale as a fuel. The report of the investigation includes the comment: "The Foord seam has had a history of being quite gassy and has resulted in explosions and fires in the mines."[12] This statement stands in stark contrast to the one made in the 1987 feasibility

[11] In debriefing notes following a mine rescue trip underground on 27 September 1992, Don Dooley reported: "Checked the dust collection system on the miner [in SW2-1 Road], in the off position, was not running at the time" (Exhibit 37b.113).

[12] Exhibit 73.3. "Nova Scotia Demethanation Project: A Coalbed Methane Content Evaluation of the Pictou Coalfield – Pictou Co., Nova Scotia" (Halifax: Algas Resources Ltd., 1981), 16.

study on the proposed Westray mine: "Methane will not be a limiting factor in the mine ventilation requirement."[13]

Algas concluded that, throughout the range of coal seams intersected, the gas contents varied from 0 to over 6 m^3/t and increased with depth. The average gas content of the Foord seam at a depth of 263 m was reported as 3.69 m^3/t. The Pictou County coals were also reported as being quite permeable, relative to western Canadian coals.[14] Further testing of coal gas content was carried out by Suncor in 1984. The values of desorbed gas in the majority of samples were reported to be in the 2.5–4.5 m^3/t range, with the highest value found at 5.7 m^3/t.[15]

Methanometers on the Continuous Miners

The Joy continuous miners used at the Westray mine were equipped with on-board methanometers (Model 420d)[16] interlinked with the main power supply. The monitoring head in this system can be installed at any suitable location for detecting methane concentrations in the vicinity of the cutting heads.[17] The digital readout unit of the 420d model is located in the machine operator's cab. Two alarm concentrations may be pre-set: at the Low Alarm concentration, an amber light flashes; at the High Alarm, a red light is also displayed and the continuous miner automatically shuts down. The device cannot be reset until the methane concentration falls below the High Alarm value and is indicated as such on the readout. The methanometer should be calibrated at regular intervals. U.S. regulations require recalibration at least every 31 days.[18] Calibration, which can be done on site, involves exposing the monitor head to known gas mixtures and adjusting the instrument settings as necessary.

The most common cause of methane ignitions in coal mines is frictional sparking at the pick points of mechanized coal-mining equipment.[19] The combined functions of a machine-mounted methanometer are to detect the presence of methane, to give an alarm

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13 Placer Development Limited, "Pictou Project Feasibility Study, volume 2: Mining" (1987) (Exhibit 10.2, p. 18). Chapter 7, Ventilation, addresses the thoroughness of the various feasibility studies as they concern methane and ventilation requirements.
Comment Regrettably, the planning of Westray ignored the lessons of mining in the Foord seam.

14 Exhibit 73.3, pp. 50–51. The dangers of this condition were still being expressed by G.P. Isenor Company Limited as late as September 1991 in its Coalbed Methane Report to Petro-Canada: "The 'gassy' Pictou Coalfield, as identified by the long history of explosions with great loss of life, can not be attributed to a high gas content of the coal, but to areas of the high permeability (fault zones, etc.) that when intersected by mining produced great volumes of methane that 'gassed out' workings. Ventilation was not able to handle this great influx of gas from these naturally fraced zones. *It should be pointed out that the New Westray mine may encounter the same problems*" [emphasis added] (Exhibit 36c.1, s. 4b).

15 Exhibit 73.1.004–06. Suncor interoffice correspondence from Arden Thompson to Edwin Fraser, New Glasgow, NS, 11 September 1984, "Preliminary Results of Methane Gas Content Testing."

16 Manufactured by General Monitors, Costa Mesa, Calif.

17 In U.S. mines, the location of the head is subject to MSHA (Mine Safety and Health Administration) approval. Nova Scotia has no restrictions.

18 30 CFR 75.342(4).

19 See figure 6.2 in Chapter 6, The Explosion.

when it reaches the Low Alarm concentration, and to shut down the machine when the atmosphere becomes dangerous. The methanometer should be well maintained. Mining machinery should never be allowed to operate without the monitoring system in operation.

Methane Problems during Active Mining

Shift foreman's reports and the testimony of miners provide ample evidence of both the presence of methane in the Westray headings and the mining delays that resulted. Methanometer readings did not appear on ventilation reports until 12 April 1992. Table 8.2 provides excerpts from shift foreman's reports that relate to gas problems in the headings during the period 20 March to 7 May 1992.

The foreman's reports indicate ongoing difficulties with gas in the continuous miner headings, escalating in the two weeks before the explosion. Westray discouraged personnel from recording in written reports occurrences of dangerous conditions. Fraser Agnew, a Westray foreman, was asked by Inquiry counsel why he failed to report on his mine examiner reports certain incidences of high gas readings and lack of stonedusting. He replied: "[W]ith the reports, if I had . . . made too many waves, I just wouldn't have been there."[20] Mick Franks, a mine electrician, discussed in testimony an incident in which his colleague Harvey Martin had recalibrated the methanometer on a continuous miner on 6 May after its "trip point" had been raised the previous day. Franks said, "I don't think Harvey would have put it in the book because it didn't look too good, you know. That's not what the company wanted to see."[21] Foreman Don Dooley related an occasion on which he had reported a high methane reading in a working heading. According to Dooley, Roger Parry, the underground manager, told him that "you can't be recording that high a reading on your daily shift reports. The mine inspector won't put up with that."[22] The testimony of mine workers complements and gives additional background to the cryptic entries in the foreman's reports.

Don Dooley described a hazardous incident in one of the North section headings that occurred some two weeks before the explosion. When the members of his crew arrived at their heading at the beginning of the shift, the auxiliary fan had been switched off. The methanometer on the continuous miner indicated a gas concentration of 6.2 per cent, within the flammable range. Before Dooley arrived at the scene, a miner had switched on the fan. About 15 to 20 minutes later, Dooley entered the heading, taking readings on his hand-held methanometer. The general body concentration within his reach remained below 1 per cent, but the machine-mounted methanometer indicated 3 per cent. The crew remained

20 Hearing transcript, vol. 35, p. 7707.

21 Hearing transcript, vol. 21, p. 4190.

22 Hearing transcript, vol. 36, p. 7851. Trevor Eagles, the engineer-in-training, said that Parry had warned him in early April 1992 "to be careful what you write down on a report, 'It could come back to haunt you'" (vol. 76, p. 16529).

Table 8.2 Gas Problems in Headings, 20 March–7 May 1992

Date (1992)	Shift foreman	Underground Operations Shift Foreman's Report – selected unedited entries
20 March	L. James	Difficult time calibrating methanometer, sensor needs to be changed ASAP
undated	F. Agnew	bolting crew down 20 min for gas.
26 March	A. Smith	Took scoop up SW gassed out half way up
31 March	(unsigned)	methanometer does not work
2 April	B. Capstick	Down clearing gas from section
8 April	B. Capstick	Installed vent tube in A and B headings and degassed. . . . degassing A heading
10 April	R. Ellis	mounted methanometer back in original position (2002 c/m)
16 April	(unsigned)	Sniffer[a] is back in original position 2002 c/m
21 April	A. Smith	Slow mining gassy.
22 April	F. Dewan	Slow mining waiting for CH_4[b] to clear
22 April	O. McNeil	Mining slow – high % of CH_4
23 April	O. McNeil	Mining slow. High CH_4
25 April	F. Agnew	lost a lot of time for CH_4 and moving supplies
27 April	L. James	4¼" × 2" bolts and nuts required to secure CH_4 sensor.
5 May	L. James	Trip point on 2002 c/m 420d raised from 1.2% to 1.5% was requested.
6 May	B. Benoit	Set up c/m gassing out . . . installed fan tube and degassed (SE)
7 May	A. Smith	Sniffer trouble sniffer cable NFG[c] Slow mining gassy.
7 May	B. Benoit	. . . gassing out had to install another fan and vent tube. Not much better . . .
7 May	F. Dewan	Sniffer needs repaired on 2002 c/m.

Source: Exhibit 37b.004–88.

a "Sniffer" refers to the methanometer sensing head
b Chemical symbol for methane
c No _____ good

outside the heading for a further 5 to 10 minutes, after which the machine methanometer reading had dropped to about 0.5 per cent.[23]

This incident involved three matters of concern. The first was that the auxiliary fan had been switched off. Not only was this action highly imprudent in such gassy conditions, as were then very obvious at Westray; it was also in contravention of section 71(9a) of the *Coal Mines Regulation Act*. Apparently, because of the noise they produced, auxiliary fans were not always in continuous operation at Westray.[24] The second dangerous aspect was the presence of a flammable gas-air mixture in a

[23] Hearing transcript, vol. 36, pp. 7832–34.

[24] When Eagles asked a mining ground-support crew why the fan ventilating a heading was not operating, he was told that "they'd turned it off because they were setting steel arches and the ground was working, and they wanted to hear the ground work, so they shut the fan off" (Hearing transcript, vol. 76, p. 16461).

heading and particularly in the vicinity of a continuous miner. The third aspect, switching on the auxiliary fan without initiating a degassing procedure, would involve the considerable risk of drawing a plug of high-concentration gas into the exhaust duct, through the auxiliary fan, and then into the main throughflow airstream. This would spread the zone containing a flammable atmosphere, increasing the probability of an ignition. A degassing procedure, although included in the Westray Manager's Safe Working Procedures, appears not to have been made known to the workforce.[25]

Don Dooley also described the adverse conditions under which mining was being conducted in the 1 Southeast section during the final week of operations.[26] Owing to the practice of series ventilation, exacerbated by uncontrolled partial recirculation, the air supplied to the Southeast section already had a general body methane concentration of 0.5 per cent.[27] On 8 May, an airflow measurement at the 30 kW auxiliary fan exhausting from the 1 Southeast heading gave 7.0 kcfm. Although that in itself was inadequate, the airflow at the inbye end of the duct would have been considerably less. Dooley described the poor condition of the duct: it had holes in it. The mining crew attempted to apply plastic patches held on with rope. This was the location in which a 15 kW forcing fan was used in an attempt to divert additional air into the entrance of the heading. The result of this entire ludicrous situation was that mining was severely inhibited by gas concentrations at the face.[28] As described by Dooley, the continuous miner would operate for a short period, during which time the reading of the machine-mounted methanometer would climb steadily to 1.4 per cent. The jib of the continuous miner would be dropped before the electrical power was automatically cut, and the machine backed out two or three metres from the face. To maintain some semblance of ventilation, the water sprays would be left on – inducing an air movement – until the floor became too wet for traction of the shuttle car. When the gas had cleared sufficiently, the continuous miner would again be advanced to cut a little more coal. The result of this intermittent procedure was that it took 20 to 25 minutes rather than the normal 45 seconds to fill a shuttle car. Under such conditions, the potential for ignition of a flammable atmosphere was very high.

The situation had been no better in the Southwest 1 section. Jay Dooley described the relocation of the methane sensors on each of two continuous miners – from the normal position by the cutting head to a point on the main body of the machine some nine feet back from the face

25 Section D of the Manager's Safe Working Procedures is entitled Manager's Procedures for Stopping and Starting Fans (Exhibit 37a. 120–22). In testimony, Don Dooley was asked whether any kind of written procedure existed for starting a fan in a high-gas situation. Dooley replied: "No sir, there was no written procedure. No, there was none" (Hearing transcript, vol. 37, p. 8275).

26 Hearing transcript, vol. 36, pp. 7835–42.

27 This situation is detailed in the section on throughflow ventilation in Chapter 7, Ventilation.

28 **Comment** This is one more example of the ad hoc, short-sighted, and incompetent undertakings, endemic at the Westray mine, that seemed to fall under the rubric "planning."

and at a fixed height from the floor.[29] The initial reason given for such a dangerous action was that the methanometer cable was being damaged. (It appears that this damage may have occurred because the cable had been situated outside the machine body rather than in its properly shielded location.) The effect of moving the sensor to its new spot was that it would then be too low and too far back to detect methane concentrations at the face, where frictional sparking takes place.[30] A further consequence was that the continuous miner would continue mining coal, without its motors being cut out automatically, when a dangerous gas concentration appeared at the cutting heads. This hazardous situation existed for several weeks before the sensors were moved back to their proper positions.

Other incidents that involved the readjusting of continuous miner methanometers are related in the section of Chapter 6, The Explosion, dealing with methanometer tampering. Repeated gassing out, methanometer breakdowns, and deliberate tampering seemed to focus on the continuous miner in the SW2-1 headings during the final days of the Westray mine.

On 7 May 1992, Wyman Gosbee was roof bolting in SW2-1. The continuous miner was mining the initial opening into the adjoining Lefthander. Gosbee testified that the methane warning light on the continuous miner was flashing almost continuously. He estimated that the machine would cut for no more than about 20 seconds at a time before shutting down.[31] The situation would appear to have been similar to that in the 1 Southeast heading described by Don Dooley.

Later during that day shift, the methanometer on that continuous miner was disabled for almost 24 hours. The following day, Gosbee was again bolting in the SW2-1 heading. He would testify that throughout that morning the continuous miner worked in the Lefthander, without the bolting crew's being asked to throttle the ventilation duct – as had been the case the previous day – to provide extra air to the mining operation.[32]

During the course of the afternoon, Gosbee observed the electrician working on the continuous miner after it had been backed out of the heading. The continuous miner recommenced operations with its replaced methanometer cable, but with an unknown effective set point for cutting power to the machine. Nevertheless, members of the bolting crew were then asked to choke off their ventilation tubing in an attempt to keep the continuous miner operating.[33]

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29 Hearing transcript, vol. 39, pp. 8580–86.

30 This, of course, is the principal safety reason for placing the methanometer sensor at the cutting head in the first place. One wonders whether this act reflected blatant incompetence or was a conscious attempt to sacrifice safety considerations to coal production.

31 Hearing transcript, vol. 25, pp. 5020–22.

32 Hearing transcript, vol. 25, pp. 5027–28.

33 Hearing transcript, vol. 25, pp. 5028–29.

Finding

At Westray, the machine-mounted methanometers and their automatic shut-off feature were regarded as a nuisance to be outwitted or eliminated, rather than as essential safety devices. The deliberate interference with the methanometers makes it clear that production of coal was to be maintained at all costs, and with blatant disregard for safety.

Finding

Any of several situations could easily have resulted in an ignition of methane leading to a coal-dust explosion. It follows, therefore, that the incident that actually caused the ignition in the early hours of 9 May 1992 was not an aberration, but simply one more in a frightening series of events that, sadly, had become commonplace at Westray.

Methane Problems during Roof Bolting

Given the inadequate ventilation in continuous miner headings, it was a frequent practice at Westray to restrict the branch of a tee-jointed duct system that exhausted air from roof bolting operations. (See the section on the use and maintenance of ducting in Chapter 7, Ventilation.) Combined with already inadequate auxiliary airflows and damaged ducting, the situation led to untenable conditions in a number of cases where miners were bolting.

In room-and-pillar mining, as practised at Westray, the working face of a heading would be advanced by a continuous miner. The machine would then be moved to an adjacent heading to repeat the operation. In the meantime, the roof bolting crew would drill holes and set roof bolts in the recently exposed roof of the first heading. The process was cyclic, with mining and roof bolting operations alternating in any given heading. The members of the bolting crew spent much of their time standing on a platform with their heads quite close to the roof and in an area where newly exposed coal surfaces were emitting methane. Given the absence of adequate ventilation, the likelihood was strong that the crew would breathe methane-contaminated air low in oxygen. (The crew would then be subject to the symptoms of oxygen deficiency, outlined at the beginning of this chapter.) A further danger would arise from the roof bolting operations themselves. The jobs of drilling holes and tightening bolts involve risks of sparking.

The roof bolting equipment was not fitted with a machine-mounted methanometer.[34] Members of the roof bolting crews were not generally qualified to carry hand-held methanometers. As Don Dooley explained, "[Y]ou have to have a coal mine . . . examiner's certificate to hold and use a methanometer in a coal mine."[35] Nor were locked flame safety lamps

34 From conversations with authorities in other jurisdictions, I gathered that it is not standard industry practice to fit bolters with methanometers.

35 Hearing transcript, vol. 36, pp. 7873–74.

available at Westray.[36] The only times at which bolting crews were able to confirm the presence or concentration of methane at their workplace was when the foreman came by and took a methanometer reading, or when a crew member showed symptoms of oxygen deficiency. Don Dooley testified that on occasion some mine examiners would "try to hide their readout from you."[37]

Lenny Bonner recalled that on 7 May 1992, while he was roof bolting in the SW2-1 heading, the methane concentration was measured at over 2 per cent.[38] The following day, Bonner worked with Wyman Gosbee on roof bolting in SW2-1. The roof was laterally inclined, and Bonner was on the high side. He found it difficult to breathe and excessively hot. At this time, the ventilation ducting had been tied off to provide additional air to the continuous miner in the adjoining heading.[39] Bonner and Gosbee untied the restricted ducting. Some 10 minutes later, the foreman, Arnie Smith, appeared and, at Gosbee's request, took a gas reading. It revealed 3.75 per cent methane. A second reading, showing 3.5 per cent, indicated that the concentration was falling.[40] Bonner's physical symptoms, occurring before the ducting was untied, likely arose from oxygen displacement by methane.

In interviews after the explosion, Doug MacLeod described incidents of "starting to get dizzy, . . . wheezy or sweaty" during surveying procedures when he was standing on the heads of a continuous miner. At times, the methane concentration was as high as 5 per cent.[41] Ed Estabrooks testified that he operated roof bolting equipment on a number of occasions when the methane concentration exceeded 5 per cent.[42] The mine workers were all too aware of the presence of methane, and at least some understood its behaviour.[43] Less certain is the degree to which they had been made conscious of the hazards associated with this explosive gas.

Other Matters of Methane in Headings and Entries

Other instances show the pervasive nature of the methane problem at Westray and the lack of expertise in dealing with it. Wayne Cheverie described the visible and audible indications of methane issuing from the freshly cut coal surfaces in the Southwest 1 section.[44] The coal was wetted

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36 Jay Dooley testified that, to his knowledge, "there was none on the property." He went on to say that by not providing a mine examiner with a locked flame safety lamp, "he cannot test for oxygen deficiency. All he has left for that now is the human body, and the human body should never be used as a tester" (Hearing transcript, vol. 39, p. 8539).

37 Hearing transcript, vol. 36, p. 7881.

38 Hearing transcript, vol. 24, p. 4783.

39 Hearing transcript, vol. 24, pp. 4785–86.

40 Hearing transcript, vol. 24, pp. 4787–88.

41 Inquiry interview, 11 June 1992, pp. 46–7.

42 Hearing transcript, vol. 24, p 4885.

43 In his testimony, Randy Facette, who was bolting in SW2-3 Road on 8 May 1992, spoke of moving the ventilation duct "into the centre of the roadway, so that it would accumulate gas from both sides of the roadway at the same time" (Hearing transcript, vol. 33, p. 7241).

44 Hearing transcript, vol. 21, pp. 4059–60.

by the dust-suppression sprays, leaving the solid faces also in a wetted condition. On entering a heading, Cheverie became conscious of a "whispering sound." He observed bubbles forming and bursting on the wet coal surfaces, a direct indication of methane being emitted from those surfaces. During his shift in the SW2-1 heading on 8 May 1992, Gosbee observed "moisture on the walls and you could see it bubbling."[45]

Westray miner Rick Mitchell described large emissions of methane in faulted areas.[46] The SW2-B heading had entered an area with prevailing roof control problems.[47] During the last night that he worked in the SW2-B heading, Mitchell experienced what he described as a "high burst of gas." After filling a shuttle car, he stopped the motors of the continuous miner, but noticed that the methanometer warning light was flashing. Although no coal cutting was then taking place, the methanometer reading continued to climb. When it reached 4 per cent, Mitchell isolated all power from the machine and left the area. He returned with the foreman. A check with a hand-held methanometer failed to indicate a high concentration of gas.

In addition to testimony by roof bolting crews, others provided indications of methane layering at roof level. Shaun Comish described being dizzy while erecting steel arches. He associated his symptons with an accumulation of methane in areas where the roof had caved.[48] Bryce Capstick spoke of gas concentrations in roof cavities "all over the mine" that would send the reading off-scale on a hand-held methanometer.[49] The prudent procedure to avoid such pooling in coal mines is to fill roof cavities with solid or foam material, or to divert a portion of the airflow with baffles. Although Eagles said that the company experimented using high-expansion foam, it appears that its use did not become common practice.[50]

John Lanceleve described a situation in which workers became dizzy from gas as chocks were being built above the arches. Lanceleve was instructed to go to the surface for a compressed-air venturi "air mover" to be used to blow air into the gas-filled cavity.[51] Employing compressed air to remove methane is expressly forbidden under section 71(10) of the *Coal Mines Regulation Act.*

Jay Dooley testified that, despite the large number of roof cavities in the mine, it was rare to test for gas at roof level outside the headings. The roof was normally out of reach for hand-held methanometers. There seems to have been on site only the one extension probe used briefly by Eagles

45 Hearing transcript, vol. 25, p. 5069.

46 Hearing transcript, vol. 31, pp. 6789–91.

47 Randy Facette testified that "the whole area up there . . . had faults running through it" (Hearing transcript, vol. 33, p. 7237).

48 Hearing transcript, vol. 28, p. 5871.

49 Hearing transcript, vol. 42, p. 9382.

50 Hearing transcript, vol. 76, pp. 16501–02.

51 Hearing transcript, vol. 27, pp. 5549–50.

in April 1992.[52] The apparent nonchalance over the absence of methanometer extension probes indicates a lack of concern over, or knowledge about, the dangers of methane layering.

The Southwest 1 Section

The Southwest 1 section was a significant source of methane, not only throughout the mining activities that took place in that section until 26 March 1992, but also during and after the withdrawal from the section. The wooden stoppings erected in SW1-B and SW1-C1 Roads on 13 April were inadequate as a seal against the escape of methane into the main intake airflow serving the newly developing Southwest 2 section of the mine.

The ventilation map of the Southwest sections at the time of the explosion (map 6 in Reference) shows the extent to which the Southwest 1 section had been developed before abandonment on 28 March 1992. The directions in which headings were driven had not been well controlled. As a result, some of the finger pillars were too narrow to support the roof.[53] Depillaring (pillar recovery) had also taken place in SW1-A Road, SW1-B Road extension, the inbye end of SW1-B Road, and SW1-A3 Road. The map does not show those depillared areas as being mined out. The combined effect was that excessive strata weight was exerted on the whole area back to SW1-3 Cross-cut.[54] As the pillars began to fail, the need for a rapid withdrawal from the area became urgent. Beginning Thursday, 26 March, the company, including all miners and equipment, was literally chased out of Southwest 1 by the failing ground.

The horror story that unfolded during those days is documented in the section on ground conditions at Westray in Chapter 10, Ground Control. Throughout the series of underground operating shift foreman's reports concerning the last days of Southwest 1, only one foreman, Arnie Smith, made reference to gas. In his night shift report of 26 March 1992, Smith noted that a Scooptram "gassed out halfway up" to the heading in SW1-A3 Road, where a continuous miner was stuck behind a collapsed rib. The crew then "repaired stopping at [SW1-A Road]." The report indicates that gas was "still clearing" at the end of the shift.[55] Pillars were failing and the ventilation system was ineffective. The gas emission rates and concentrations must have been elevated, yet, quite remarkably, this is

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52 Jay Dooley commented on the lack of a probe: "I strongly feel [it] . . . hindered my performance as far as gas testing" (Hearing transcript, vol. 39, pp. 8537–38).

53 Eagles commented that in the Southwest 1 section, "the drifts were weaving back and forth somewhat and 12 metre pillars ended up being 5 and 6 metres in some areas." Eagles attributed this sloppiness to poor supervision. "It doesn't really take any longer to drive a drift on line than it does to drive it off line," he told the Inquiry, "It's the shift boss's responsibility" (Hearing transcript, vol. 76, pp. 16471–72).

54 In Eagles's opinion, "the depillaring was very sporadic and unorganized." The weight that should have been taken by a properly depillared cave area was instead taken by the existing pillars, which weren't substantial enough. (Hearing transcript, vol. 76, pp. 16473–75).

55 Exhibit 42f.0174.

the only comment on gas in the foreman's reports during the withdrawal period.

The lack of reference to gas concentrations in the foreman's reports has left little quantitative information on what the methane levels actually were during the final days of mining and the withdrawal from Southwest 1. There is a great deal of anecdotal evidence on the gas emissions that took place in Southwest 1 before and after the withdrawal. Ray Savidge gave evidence of having found over 5 per cent methane in SW1-4 Cross-cut, the return from the active headings, during a time when mining was going on in that section.[56]

Abandonment

The withdrawal from Southwest 1 was fraught with danger for the entire workforce present in the mine. The combination of failing pillars, high levels of gas emissions, operating mechanized equipment, and mining up to the last possible moment added up to a potent recipe for disaster. It seems that the production of coal, coupled with the reclamation of equipment, took precedence over the safety of the workforce.[57] These priorities gave rise to grave concerns expressed by David Waugh, the engineering superintendent.[58]

Following the withdrawal from the Southwest 1 section, the area continued to fill up with methane, commencing in the higher-elevation areas and moving downhill. On 29 March 1992, Eagles measured a methane concentration of 5 per cent, the limit of his methanometer, in SW1-4 Cross-cut inbye SW1-B Road.[59] On 28 March, Roger Parry telephoned mine inspector Albert McLean, informing him that weight had come down in SW1-A1 and SW1-A2 Roads. McLean visited the Southwest section on 31 March. His subsequent memorandum to his boss, Claude White, director of mine safety, on 2 April 1992, does not indicate the route of his inspection.[60] He wrote of methane concentrations of 1 to 4 per cent having been recorded, but did not indicate that he, personally, took any methanometer readings. His memorandum includes the sentence: "The methane is coming in waves." The seriousness of what had occurred and was ongoing appears not to have been appreciated by the inspectorate.

Shortly after the abandonment of Southwest 1 and before the stoppings were built in SW1-B and SW1-C1 Roads, probably within the first few days of April 1992, Roger Parry asked Jay Dooley to check gas and

[56] Hearing transcript, vol. 22, p. 4339.

[57] According to Eagles, "[t]hat day when the place started falling apart and we were getting high gas levels, the mine should have been evacuated" (Hearing transcript, vol. 76, p. 16645).

[58] Eagles knew that Waugh was upset about the way the Southwest 1 had been abandoned (Hearing transcript, vol. 76, p. 16635), and that Waugh had had an argument with Roger Parry about how the area was depillared (p. 16505).

[59] Hearing transcript, vol. 76, pp. 16519–20. Knowing that a significant amount of methane was in this relatively low part of Southwest 1, Eagles said, "[U]p in the top part of the area, it was filling up with gas, so I assume there were really high levels of methane in the high part [to the North and West]" (p. 16476).

[60] Exhibit 73.4.

ventilation conditions in that area. Dooley, who had a high-range (0 to 100 per cent) methanometer, was accompanied by Owen McNeil.[61] Inbye SW1-3 Cross-cut on SW1-B Road, the air movement was outward – towards the mains – and the general body gas concentration was 0.3 to 0.4 per cent. Air was issuing from SW1-4 Cross-cut into SW1-B Road at 0.3 to 0.4 per cent methane. On moving up SW1-4 Cross-cut to the intersection with SW1-A Road, the general gas concentration remained between 0.4 and 0.6 per cent, indicating that an airflow circuit had been maintained around SW1-8 Cross-cut and back through SW1-A Road. However, a methanometer reading in SW1-4 Cross-cut just inbye SW1-A Road gave a concentration that was at least 60 per cent, indicating that there was no airflow circuit in existence inbye SW1-A Road. At this time, the observers left the area promptly. They were impressed that the concentration could change from 0.6 to over 60 per cent within such a short distance. This was, in fact, a normal consequence of the buoyancy of methane and the upward inclination of SW1-4 Cross-cut.

The Stoppings in SW1-B and SW1-C1 Roads

Following the abandonment of the Southwest 1 section, the entrances to it – SW1-B and SW1-C1 Roads – remained open. A third entrance, through 2NA Road, was inaccessible because of a roof fall. A measurement taken on 2 April 1992 indicated that the airflow entering the Southwest 1 section at that time was approximately 21 kcfm (see table 7.1 in Chapter 7, Ventilation). The observations by Dooley and McNeil indicate that the probable route of this airflow was in through SW1-C1 Road, across SW1-5, SW1-6, and SW1-8 Cross-cuts to SW1-A Road, returning via SW1-A Road and SW1-4 Cross-cut to SW1-B Road. A wood-and-plastic stopping had been erected in SW1-B Road inbye SW1-4 Cross-cut.[62] The rate of airflow to ventilate the Southwest 1 section was inadequate, even if the pillars and stoppings within the section had not been collapsing. However, that same airflow would have promoted the flow of methane, as a roof layer, from the intersection of SW1-A Road and SW1-4 Cross-cut, towards and out through SW1-B Road.

The stoppings in SW1-B and SW1-C1 Roads inbye SW1-3 Cross-cut, built on 13 April 1992, were first reported in Eagles's ventilation reports on 15 April.[63] The stoppings comprised ¼-inch plywood sheets nailed to the chocks that had been built as additional roof support at those locations.[64] The ground control difficulties had also necessitated setting steel arches in SW1-B Road all the way from the stopping to beyond the

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61 Hearing transcript, vol. 39, p. 8598.

62 Exhibit 37a.076.

63 Exhibit 37a.084.

64 Jonathan Knock described the construction of the stopping (Hearing transcript, vol. 26, pp. 5285–86). Don Dooley, who was responsible for building some of those chocks, testified that he "didn't know that it was going to be a stopping. I was under the impression that I was just trying to support this intersection" (vol. 36, p. 7957).

intersection with SW1-3 Cross-cut.[65] A large fall had previously occurred at the junction of SW1-B Road and SW1-3 Cross-cut.[66] Quite apart from the flimsy nature of the stopping, there was adequate space for a methane layer to flow over the arches at the stopping and out along SW1-B Road. Wayne Cheverie was sufficiently concerned about the state of the roof that he was reluctant to enter the part of SW1-B Road leading to the stopping.[67]

No sealant or cement was used in the construction of the plywood stoppings. Eagles described the gaps as large enough to "fit your hand through."[68] These stoppings reduced the airflow in Southwest 1 to the quantity that could leak through them, allowing the high-concentration gas to fill up the entries in SW1-A Road and SW1-4 Cross-cut and encroach on the back of the stopping in SW1-B Road. That stopping was incapable of resisting the escape of methane into the Southwest 2 intake. *Prudent practice would have dictated the construction of explosion-proof seals in each of the three entrances to the abandoned section.* Each seal would have consisted of two concrete-block or masonry walls several metres apart and keyed into roof, floor, and sides, with the intervening space filled tightly, from floor to roof, with inert material.[69]

The presence of a methane layer emerging from Southwest 1 was illustrated by reactions of personnel working in SW1-B Road. During the construction of the chocks, one worker became dizzy and fell when he was near roof level.[70] Jay Dooley knew of no checks for methane having been made in the vicinity of the stopping.[71] Aaron Conklin said that one of his fellow workers passed out during the building of the SW1-B Road stopping, when the airflow around Southwest 1 would have been decreasing.[72] The gas concentration would have risen and may have reached high levels as the plywood was progressively applied.

The failure of pillars in Southwest 1 caused ground movement at least as far out as SW1-3 Cross-cut, which did not cease when the section was abandoned. The already leaky stoppings in SW1-B and SW1-C1 Roads became even less capable of controlling the outflow of methane. The load on the chocks in SW1-B Road forced them into the floor, causing the immediate floor strata to fail. A crack appeared in the floor at the front of the stopping.[73] The convergence of roof and floor caused the plywood to buckle, and a seam opened up "about seven feet off the floor . . . about four to six inches in length . . . and an inch, maybe two inches wide."[74]

65 Exhibit 45.7.

66 Exhibit 45.15.

67 Hearing transcript, vol. 21, p. 4035.

68 Hearing transcript, vol. 76, p. 16480.

69 This preferred construction is in stark contrast to the flimsy plywood-and-plastic structures that were put in place.

70 Harvey Martin observed this incident (Hearing transcript, vol. 23, pp. 4538–39).

71 Hearing transcript, vol. 39, p. 8770.

72 Hearing transcript, vol. 28, p. 5965.

73 Jay Dooley described "a crack in the floor approximately two inches" and "about five to six feet away from the stopping" (Hearing transcript, vol. 39, pp. 8613–14).

74 Jay Dooley (Hearing transcript, vol. 39, p. 8615).

The buckling of the stoppings was recorded in Eagles's weekly ventilation reports of 23 April and 29 April.[75] Eagles described the holes in the buckled stoppings as ones that "you could, if you really wanted to, probably stick your head through."[76]

A wealth of evidence exists on the emission of methane from Southwest 1 along SW1-B Road both before and after the stopping was built. On 2 April, Eagles measured a methane concentration of 2.5 per cent seven feet above the floor at the location where the SW1-B Road stopping would be built. He also observed what he described as a "pothole" in the roof, which may have reached 15 feet from the floor. Using a methanometer extension probe, he measured 9 per cent methane in that cavity, close to the maximum explosibility of a methane-air mixture and an indication of methane layering.[77] On 8 April, at approximately the same location, Eagles measured 4 per cent methane at about 7.5 feet from the floor. The roof was some 12 feet high.[78] Again, this measurement strongly suggests methane layering. By 29 April, an airflow estimated at 5 kcfm was observed leaking through the SW1-B Road stopping, with general body gas concentrations at arm's height varying between 1.25 and 2.5 per cent at a location 3 m from the stopping.[79]

During an inspection of the SW1-B Road stopping, Jay Dooley found 0.4 to 0.5 per cent methane from SW1-3 Cross-cut towards the stopping. Within an arm's length of the stopping, his methanometer reading climbed rapidly. To prevent damage to the methanometer, he switched it off when the reading reached 3 per cent.[80] Dooley became anxious about the extent to which methane was emerging from the Southwest 1 section and, at the end of his shift, voiced his concerns separately to Roger Parry and Gerald Phillips.[81]

Other workers in the mine were concerned about the emission of methane from the old workings. Mine examiner Fraser Agnew measured 3.5 per cent methane at the SW1-B Road stopping and discussed this reading with Parry. However, Agnew considered it to be such "common knowledge to Roger and everybody else" that it required no mention on his examiner's report.[82] Electrician Harvey Martin described accompanying Owen McNeil to the SW1-B Road stopping and finding a gas concentration that exceeded the limit of a 0 to 5 per cent methanometer.[83] Mick Franks described a similar experience when

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75 Exhibit 37a.087, 074, respectively.

76 Hearing transcript, vol. 76, p. 16599.

77 Hearing transcript, vol. 76, pp. 16525–26.

78 Hearing transcript, vol. 76, pp. 16537–38.

79 Exhibit 37a.074.

80 Dooley explained that, with the hand-held methanometer that measures 0 to 5 per cent, "if you let the needle go to 5 per cent, the machine is taken out and recalibrated. It won't give you a proper reading" (Hearing transcript, vol. 39, pp. 8615–18).

81 Hearing transcript, vol. 39, pp. 8619–20.

82 Hearing transcript, vol. 35, pp. 7697, 7704–05.

83 Hearing transcript, vol. 23, pp. 4489–90.

accompanied by his foreman, John Bates.[84] Franks also observed "polythene sheet" having been wedged into the gaps around the SW1-B Road stopping in a vain attempt to reduce the gas outflow.[85]

Methane Emission from the Abandoned Southwest 1

From the actions and observations described, we can infer movements of high-concentration methane in the abandoned Southwest 1 section. At the time of Jay Dooley's trip into Southwest 1, on about 2 April 1992, the stoppings in SW1-B and SW1-C1 Roads had not yet been built. The situation is illustrated in figure 8.4. An airflow of approximately 21 kcfm entered Southwest 1 through SW1-C1 Road. It traversed a route that encompassed SW1-8 Cross-cut, SW1-A Road, and SW1-4 Cross-cut before exiting via SW1-B Road. This airflow route enabled Dooley to reach the intersection of SW1-A Road and SW1-4 Cross-cut without encountering unduly high concentrations of methane in the general body of air. However, all areas to the high west side of that route had become filled with methane. It was at the fringe of this large body of gas in SW1-4 Cross-cut, at the intersection with SW1-A Road, that Dooley encountered methane in excess of 60 per cent. Although the general body gas concentration was acceptable outbye that point, a layer of methane flowed along the roof out to SW1-3 Cross-cut. It was this gas that created difficulties for the builders of the chocks and, later, the stopping in SW1-B Road.

Figure 8.5 illustrates the situation that developed after the construction of the stoppings in SW1-B and SW1-C1 Roads. In the absence of an effective ventilation circuit in Southwest 1, the high-concentration methane encroached on SW1-B Road from the higher-elevation entries. A small amount of air continued to leak through the SW1-C1 stopping, discouraging methane from emerging at that location. The leakage, which had increased to about 5 kcfm by 29 April because of buckling plywood on the stoppings, was still insufficient to prevent high-concentration methane from reaching the rear face of the stopping in SW1-B Road. Brian West of the Bank of Nova Scotia testified to visiting the stopping with Phillips, who estimated the gas concentration behind the stopping to be about 80 per cent and, therefore, inert.[86]

The rapid increase in methane concentration observed close to the outer face of the SW1-B Road stopping was due to the upward free-streaming effect (discussed earlier and illustrated in figure 8.2). SW1-B Road had little air movement inbye SW1-3 Cross-cut after the stopping was erected. Although some of the methane would diffuse into the air, increasing the general body concentration, the majority of it rose to the

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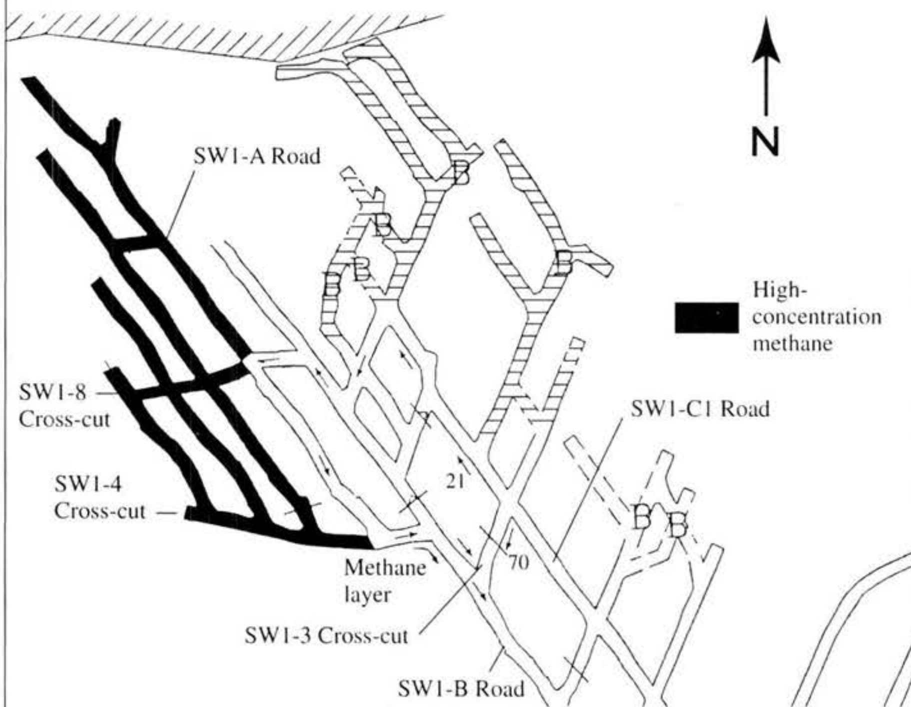
84 "John took his spotter and put it back against the plywood and . . . the needle just buried itself" (Hearing transcript, vol. 21, p. 4151).

85 Hearing transcript, vol. 21, p. 4149.

86 Hearing transcript, vol. 49, pp. 10752–53.

Figure 8.4 Methane in Southwest 1, 2 to 13 April 1992



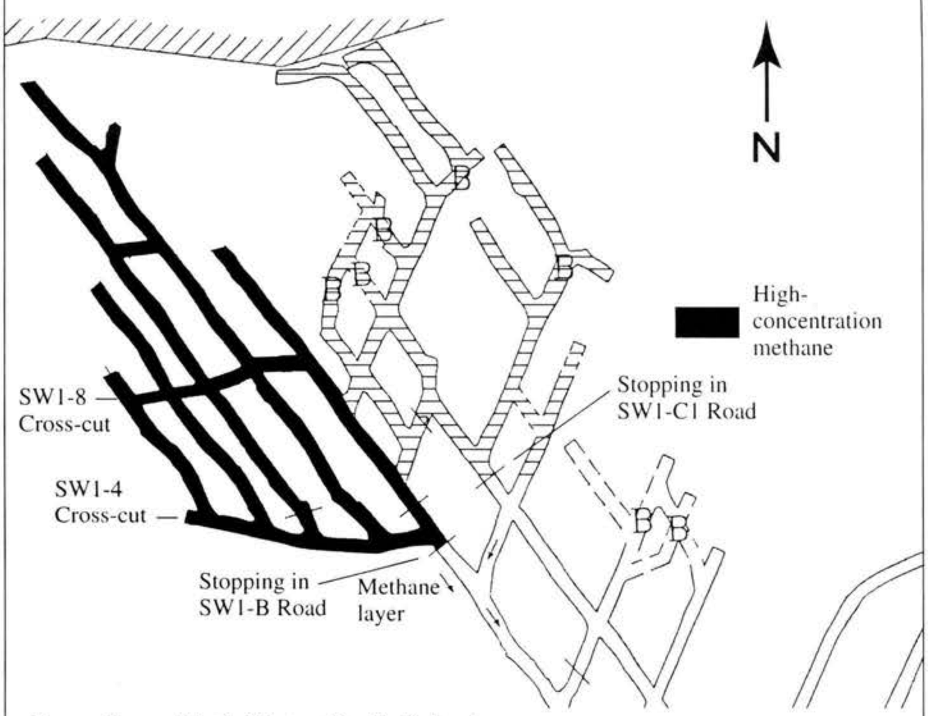
Note: Ventilation airflow quantities are given in kcfm.

Source: Prepared for the Westray Mine Public Inquiry by Dr Malcolm J. McPherson.

roof and flowed outward as a methane layer towards SW1-3 Cross-cut (see figure 8.6).

Once the high-concentration methane had reached the back of the stopping, the total rate of emission into the main ventilation system would have been approximately the same as before the stopping had been built, apart from small variations due to fluctuations in barometric pressure. However, the important difference was that the methane now emerged primarily as a high- concentration roof layer, with much less mixing into the general body than had been the case before the stoppings were built. The effect was observed by mine examiner Bryce Capstick, who testified that "when the temporary seals went up into those sections [Southwest 1], that's when we started having the gas problems when we started into the

Figure 8.5 Methane in Southwest 1 after Stoppings Built [a]



Source: Prepared for the Westray Mine Public Inquiry by Dr Malcolm J. McPherson.

a The stoppings in SW1-B and SW1-C1 Roads were built on 13 April 1992.

Southwest 2."[87] Capstick's observation was an indication that the methane layer from Southwest 1 reached and extended into the Southwest 2 development.

The rate at which methane was produced in, and escaped from, Southwest 1 can be assessed for the date of 2 April 1992. Observations made by Eagles and recorded in his report for that day indicate that the airflow proceeding inbye on SW1-C1 Road beyond SW1-3 Cross-cut was 20.9 kcfm.[88] Because this figure does not take into account any air that passed over the fall in 2NA, the airflow returning from Southwest 1 via SW1-B Road would have actually been somewhat higher. That return air had a general body concentration of 2.5 per cent, while a reading in a roof cavity showed 9 per cent. Using the general body concentration only, the volume of methane emerging from Southwest 1 was at least 522 cfm ($0.246\ m^3/s$).[89]

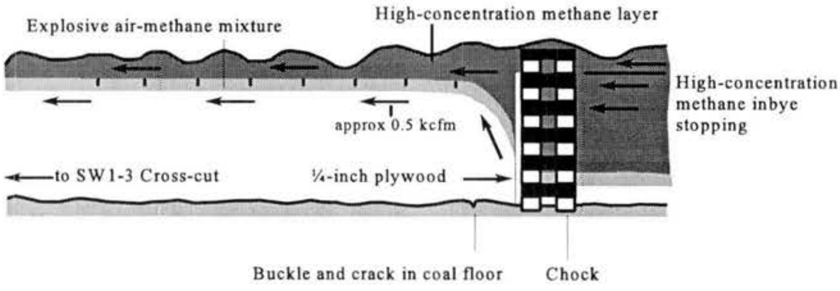
Chapter 6, The Explosion, discussed the effects of falling barometric pressure in the hours preceding the explosion. That factor added a further

87 Hearing transcript, vol. 42, p. 9429.

88 Exhibit 37a.075.

89 This is calculated by the formula $2.5/100 \times 20{,}900$ cfm = 522.5 cfm.

Figure 8.6 Section across Plywood stopping in SW1-B Road End of April 1992



Source: Prepared by Malcolm J. McPherson for the Westray Mine Public Inquiry.

18 cfm of methane to the volume emerging from Southwest 1. The rate of gas emission due to expansion, although small compared with the amount of gas being produced on 2 April 1992, was significant. The importance of the barometric changes is that they assisted rather than inhibited the emission of methane from Southwest 1 for almost two days prior to the explosion. The rate of emission in old workings normally declines slowly over time. The rate of decline depends primarily on the permeability of the strata and the gas content of the coal. We know that the Foord seam was highly permeable and that the workings in the Southwest sections were close to faults. This proximity likely further increased the permeability of the strata and allowed gas to migrate towards the openings from greater distances. In such circumstances, the emission rate from the Southwest 1 section would remain substantial for an extended time. Apparently, mine management had some discussion about draining methane from the Southwest 1 section. At one point, Jay Dooley understood that Phillips "was going to initiate the methane drainage system over top of 4 Cross-cut."[90] On 8 April, Phillips told Colin Benner, Curragh's president of operations, that "plans were to install an exhausting system to bleed the methane-laden air out of there."[91]

The methane layer that came from the stopping in SW1-B Road flowed along the roof and in cavities above the arches to arrive at the junction with SW1-3 Cross-cut, where a large fall had occurred.[92] The methane would fill the cavity in the roof, while the natural incline of the roof would protect the methane layer against disturbance from the air arriving through the cross-cut.

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90 Hearing transcript, vol. 39, p. 8622.

91 Benner (Hearing transcript, vol. 73, pp. 15866–67). Eagles also recalled a discussion about "possibly drilling a hole into the area to try to drain it from the top side, which never happened" (vol. 76, p. 16530).

92 Map 8 in Reference documents roof falls and overbreak in the Southwest section.

The layer would proceed outbye along SW1-B Road until it reached SW2-B Road, the ascending intake to the Southwest 2 section. The roof of that entry was also inclined laterally, having a height of 14.5 feet on one side and 11.5 feet on the other.[93] The layer would ascend SW2-B Road, favouring the higher side of the entry. There can be little doubt that a large layer of methane flowed up the roof of the SW2-B Road, carrying the gas towards the active headings.[94] It is probable that this situation existed from the time the stopping in SW1-B Road was built.

The Explosive Environment at Westray

Finding

The problems associated with methane gas at the Westray mine originated with a failure to recognize the significance of the permeability of the Foord seam, and in not giving due consideration to the mining history of the Pictou coalfield. They ended with the explosion on 9 May 1992. Between those two points in time, there is a sad litany of causal factors relating to the emissions of methane at Westray and the attempts made to maintain coal production within poorly and incompetently managed ventilation systems. The following circumstances, which existed at various times and at various locations throughout the mine, coupled with the apparent management attitude of "coal production at any cost," provided the environment that would convert a spark at the continuous miner heading into a rolling methane fire and explosion:

- **failure to plan adequately for substantial emissions of methane or to take into account the historical evidence of such emissions;**
- **continued mining in areas where pillars were crushing, hence producing higher quantities of gas;**
- **falling barometric pressure for 42 hours prior to the explosion and the resulting increase in gas emission;**
- **failure to maintain a barometer on the surface of the mine to track changes in atmospheric pressure;**
- **insufficient ventilation in headings to dilute methane efficiently;**
- **inadequate air velocities to promote mixing of the gas or to inhibit the formation of methane layers;**
- **use of series ventilation, which resulted in a loss of air quality;**
- **uncontrolled partial recirculation of air within the ventilation structure;**
- **failure to keep auxiliary fans operating continuously;**
- **failure to employ a degassing procedure before switching on an auxiliary fan when a flammable atmosphere had been observed in a heading, contrary to company guidelines;**
- **inadequate ventilation ducting, which was allowed to fall into disrepair;**

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93 Exhibit 45.07.

94 Malcolm McPherson has calculated that air velocity in SW2-B Road would have had to be at least 715 feet per minute to prevent methane layering if the gas emissions remained at the 522 cfm measured on 2 April 1992. The actual velocity measured on 23 April was less than half that, at 322 feet per minute (Exhibit 37a.085). The method for calculating air velocity to prevent methane layering is detailed in McPherson, *Subsurface Ventilation*.

- **obstruction or constriction of ventilation ducting in headings being roof bolted, to keep the continuous miner from gassing out in adjoining headings;**
- **travelling of intake air past the entrances to old workings – particularly the Southwest 1 workings, which were known to contain large volumes of methane and were improperly sealed;**
- **relocation of machine-mounted methanometer monitor heads away from their correct location on the continuous miner jibs, thus defeating their purpose;**
- **interference with the set points or readouts of continuous miner methanometers so that the machine would operate in higher concentrations of methane;**
- **operation of a continuous miner with no machine-mounted methanometer;**
- **operation of roof bolting equipment where methane layers existed to the extent that workers near roof level presented symptoms of oxygen deficiency;**
- **failure to keep dust scrubbers operating at all times when a continuous miner was working;**
- **use of compressed air equipment to remove methane from a roof cavity;**
- **failure to provide roof bolting crews with the means of detecting methane;**
- **failure to contain methane accumulation in an abandoned area by adequate seals, or to control it by adequate ventilation;**
- **failure to detect and control a layer of methane issuing from an abandoned area;**
- **inclined workings that promoted methane accumulations in the higher elevations without the necessary air velocity to disperse this accumulation;**
- **falls of ground that left roof cavities in which methane could accumulate without any attempt to clear those cavities or fill them;**
- **inclined entries that facilitated the upward progression of methane layers;**
- **failure to check for methane layers or to provide the equipment necessary to perform such searches; and**
- **an appalling lack of safety training and indoctrination, especially respecting new underground miners, on the general properties of methane and its propensity to rise to the roof and form layers that at some point would be explosive.**

It should be understood that not all these conditions were necessary, at any one time, to provide the explosive environment that was present on 9 May 1992. They are all listed here to give some indication of the laxity, or the incompetence, or the apathy, or the carelessness that seemed to permeate Westray management and in turn to have a negative effect on the underground workers, who were lulled into a sense of "it can't be all that bad."

The attitude of Gerald Phillips towards the methane problem is both difficult to understand and dangerous: difficult to understand because his early training in the United Kingdom would have trained him in the perils of dealing casually with methane; dangerous because his casual attitude permeated Westray management, creating and perpetuating a serious safety defect. Phillips, by his training and experience, must have known better.

Methane Control

Detection and Monitoring

Since methane is a colourless and odourless gas, it is impossible to detect it with the eye or the nose. Therefore, some method to alert the miner to the presence of methane in the mine, and to give the workforce the chance to take remedial action, had to be devised. The earliest detectors were the open flames that miners used for lighting underground. All too often, the flame would cause an explosion.

Several other testing devices received varying degrees of acceptance until the introduction of the locked flame safety lamp. As described by one training handbook:

> The locked flame safety lamp is the principal monitoring and detection instrument that mine examiners and shotfirers have at their disposal. . . .
>
> Locked flame safety lamps were originally developed to provide a safe means of illuminating coal mines. However, soon after their introduction for this purpose, it was discovered that the lamp flame responded in characteristic ways to both the presence of methane and the absence of oxygen.[95]

Normally, the flame of the safety lamp burns yellow. When methane is present in the air, the flame will burn with a bluish cap on the yellow flame, and the flame will become more elongated. Since the length of the flame is in direct proportion to the concentration of methane in the air, it presents a good testing mechanism for the presence of the methane. The glass globe of the lamp may be marked with gradient rings so that the user can read the percentage of methane in the atmosphere. The safety lamp is also used to test for oxygen deficiency. The lamp will not burn at all below 16 per cent oxygen in a methane-free atmosphere and loses about two-thirds of its light output at 19 per cent oxygen.

In Nova Scotia, section 72(1) of the *Coal Mines Regulation Act* directs the use of a "locked flame safety lamp or other gas tester of type or pattern approved by the Minister." In Nova Scotia, the threshold limit value (TLV) for methane is 1.25 per cent.[96] At the Devco operations in Cape Breton, which are governed by regulations made pursuant to the *Canada Labour Code*, the TLV is also 1.25 per cent.[97] The TLV of 1.25 per cent

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95 Cape Breton Development Corporation, *Mine Examiner/Shotfirer Training Programme*, Module C/MO 4/3 (1987), 11.

96 For the purpose of this discussion, we use the term "threshold limit value" to mean the percentage of methane in the air above which, by regulation, diesel and electrical equipment may not be operated. The relevant sections in the act are section 84, rule 5(d) and section 85(2), rule 2.

97 Canada, *Coal Mines (CBDC) Occupational Safety and Health Regulations*, SOR 90–97, s. 130.

is by no means an arbitrary percentage. I have been informed that this limit was dictated by the fact that the locked flame safety lamp could not register a lower methane reading.[98]

In the United States, the TLV is 1.0 per cent. It is also noteworthy that in the United States the locked flame safety lamp has been authorized only for supplementary testing for oxygen deficiency.[99] It may be assumed that in the United States the TLV was lowered as a result of the introduction of more accurate methane detection devices capable of recognizing concentrations lower than the 1.25 per cent. The various digital solid state methane detection devices now on the market are referred to generically as methanometers. They are smaller, more compact, safer, and more accurate than the locked flame safety lamp. The MSA Spotter illustrated in photograph 10 in Reference was used by supervisors at Westray. This portable hand-held device accurately measures 0 to 5 percent methane in the tested air.

The Spotter can be fitted with a detachable probe that extends up to 21 feet (6.4 m) so that gas concentrations in roof cavities and other remote areas can be detected and measured. The Spotter and similar devices are designed to measure varying concentrations of methane (another common range is 0 to 100 per cent) on a "spot" basis. That is, the operator holds the sensing head or probe in the air to be sampled, presses a button, and reads the result on a needle scale or digital output. Other devices are designed to measure oxygen, carbon monoxide, or any combination of the threes gases.[100]

Other gas monitors are designed to sample the air continuously, usually giving a visual or an audible alarm beyond a pre-set limit. Such monitors are either portable and can be hung temporarily in a working area, or they can be permanently mounted on equipment such as the continuous miner or electrical switchgear. The latter are often capable of opening an electrical circuit to shut down equipment.

The modern coal mine is also equipped with electronically controlled remote sensors strategically located throughout the mine to take continuous readings of methane, oxygen, smoke, and noxious gases. The sensing devices have audible alarms at the site, and the readings are transmitted to a central control monitor and recorder. The system installed at Westray is described in Chapter 5, Working Underground at Westray.

Degasification – Methane Extraction

The problem of methane control in coal mining has been of paramount importance throughout the world's coal mining community, with both

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98 Conversation with Ian Plummer, provincial coordinator, Ontario Ministry of Labour, Mining Health and Safety Program; since confirmed by other consultants and officials.

99 30 CFR 75.320(d).

100 I was introduced to an impressive array of gas-testing instruments during my visit to the National Mine Health and Safety Academy in Beckley, West Virginia. At one time, coal miners commonly used canaries to detect carbon monoxide. Special cages enabled the birds to be resuscitated from exposure to CO with a shot of oxygen.

government and industry devoting considerable time and resources to its study. Methane control has been the subject of many conferences, seminars, and symposiums. The amount of written material, including learned papers, scientific studies, and industry reports, is overwhelming.

One area of continuing study and research concerns the extraction of methane prior to mining. Coalbed methane (CBM) extraction is technologically advanced and has both a safety and an economic component. Russell A. Carter, western field editor of the periodical *Coal*, wrote that "CBM has been recognized as a potential energy source since the mid-1970s and is commonly extracted for its fuel value in Europe and elsewhere."[101]

Carter quotes Charles Dixon, vice-president of mining engineering for Jim Walter Resources (JWR): "If we didn't have a degasification program, we couldn't operate our mines economically." Dixon's company is a 50 per cent partner in Black Warrior Methane Corp. (BWMC) of Brookwood, Alabama. BWMC made its first delivery of commercial-grade methane to the Southern Natural Gas Company in February 1982. Between then and April 1996, BWMC produced over 135 billion cubic feet of pipeline-quality methane extracted from wells in the vicinity of the four JWR underground coal mines in the Brookwood area. Sixty-five billion cubic feet of that gas (worth $250 million) came from gob wells alone, gas that otherwise would have had to be removed from mined-out areas via the mines' ventilation systems, at greatly added expense. The other 70 billion cubic feet came from "standard" vertical coalbed methane wells drilled from surface years ahead of mining, and from horizontal degasification in advance of longwall mining.[102]

Dixon, in a paper presented to a 1987 symposium on coalbed methane, expressed enthusiasm for JWR's experience with degasification:

> The improvements in continuous miner productivity which have resulted from horizontal degasification, and have been noted previously, have been significant. However, the greatest effect has been on the longwall faces. The benefits have been from (1) increased face production resulting from less downtime from high methane concentrations and from high cutting rates [and] (2) longer face lengths which have been allowed because of the reduced methane content of the coal.
>
> The management of JWR is convinced that horizontal degasification is a viable, efficient, and economical technique and is committed to a mining system where it is an integral part.[103]

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101 Russell A. Carter, "Methane Fever Flares in 1990," *Coal* (November 1990): 65–68.

102 This information is from materials supplied to me by BWMC. Gerry Sanders, president of BWMC, told me that commercial-grade methane extraction from the JWR mines accounts for less than half the methane produced by the mines. The remainder is cleared from the mines through normal ventilation.

103 Charles A. Dixon, "Coalbed Methane – A Miner's Viewpoint," *Proceedings* of the Coalbed Methane Symposium (Tuscaloosa, Ala. 1987)

The advantages of gas drainage are more than economic. As stated in a 1985 paper from Australia:

> There are three reasons for considering seam gas drainage.
> 1. To pre-capture normal seam gas emissions before their mixture with mine atmospheres exceeds the statutory maximum.
> 2. To minimize dangers arising from intermittent sudden and large volumes of seam gas being liberated into openings.
>
> . . .
>
> 3. To exploit the seam gas commercially.[104]

In commenting on the results of tests on seam gas drainage at the Metropolitan colliery in Australia's Sydney Basin, the authors stated:

> In all five pre-drained headings, substantial reductions in the working face gassiness were recorded, totally obviating the necessity for shotfiring. In contrast, the undrained control heading required continuous full face firing as a result of consistently high gas emission values. Results provided strong evidence that in certain circumstances, pre-drainage under suction . . . greatly improved mining conditions by significantly reducing seam gas content, providing greater roadway stability and allowing a much more acceptable advance rate.

According to a European handbook, "[s]ystematic drainage of firedamp [methane] began at Mansfield Colliery in the Ruhr in 1943."[105] Methane drainage clearly had an economic component:

> [T]he principal direct use of firedamp occurs at or near the centre of production with firedamp being burnt in colliery and power-station boilers or drying kilns. In view of the scarcity and cost of energy, however, these applications [traditional natural gas users] are still attractive and are again on the increase.

But safety remains the principal consideration in the removal of methane from coal mines. As the European handbook stated:

> There must be no doubt, however, that the main reason for firedamp drainage continues to be for safety, because it makes a substantial contribution to the improvement and safety of underground mining by reducing firedamp concentrations in return airways, working areas and travelling roadways of the mine. It also provides increased safety during the working of high-output faces, because it is practicable to extract large quantities of gas which would otherwise have to be mixed with large volumes of air. It would be extremely difficult to circulate such large quantities of air through most working places without raising clouds of dust, inconsistent with health standards currently in use.[106]

This point raises an important issue. High-volume coal extraction methods, such as longwall or room and pillar, can be impeded by an inability to dilute the methane produced at the mining face to safe levels.

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104 Alan J. Hargraves and Leszec Lunarzewski, "Review of Seam Gas Drainage in Australia," *Proceedings of the Australasian Institute of Mining and Metallurgy* 290 (February 1985): 55–70.

105 Coal Directorate of the Commission of the European Communities, *Firedamp Drainage – Handbook for the Coalmining Industry in the European Community* (Essen, Germany: Verlag Glückhauf GmbH, 1980), 20 [*Firedamp Drainage*].

106 *Firedamp Drainage*, 20–21.

In other words, production slows down, so that the volume of released methane can be properly and safely dissipated. This facet of the problem is well known in the industry. The following is taken from the *SME Mining Engineering Handbook:*

> Typically, as methane emissions increase on a section, more air is directed to the section to dilute the gas. However, as coalbeds with higher gas contents are exploited in conjunction with the demand for ever-increasing production rates, the mine ventilation engineer may find that it is not possible to direct a sufficient amount of air onto the section to ensure the safe extraction of the coal. To enable the mine to maintain production, various techniques were developed to remove gas from the coal. These techniques include drainage from horizontal, vertical, and directionally drilled boreholes.[107]

In recent years, the thrust in the United States seems to have been to exploit coalbed methane, not only for the purpose of making coal mining safer and more efficient, but for the economic value of the gas itself. A 1987 article in the *Journal of Petroleum Technology* identified six major coalbed basins of interest in the United States:

> The current level of activity and interest in coalbed methane development is focused in six basins. These include three eastern basins with shallow coals (Northern Appalachian, Central Appalachian and Warrior) and three western basins with deep coals.[108]

Charles Byrer, one of the authors of that article, is a geologist with the U.S. Department of Energy (Unconventional Gas Projects branch). He said in conversation that the Nova Scotia coalfields such as the Cumberland basin and the Pictou coalfield are geological extensions of the Appalachian basins and that they would therefore have similar geological characteristics, including faulting and methane content.[109]

Coalbed methane control and exploitation in Nova Scotia go back several decades. Gary Ellerbrok, a Devco project manager, reported in 1984 that methane drainage for safety reasons commenced in the Sydney coalfield in 1969 at the No. 12 Colliery.[110] In his abstract to the paper, the author stated:

> Methane gas, produced as a byproduct of underground coal mining, is now being treated in a new light in the Sydney Coalfield, off Cape Breton Island, Nova Scotia. Until recently, the emphasis was on diluting the gas to tolerable concentrations or collecting the gas and discharging it at points underground where dilution was easily accomplished.

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107 *SME Mining Engineering Handbook*, 2nd ed., vol. 2, ed. Howard L. Hartman (Littleton, Colo.: SME, 1992), s. 22.5.1, p. 1939.

108 Charles W. Byrer, Thomas J. Mroz, and Gary L. Corvatch, "Coalbed Methane Production Potential in U.S. Basins," *Journal of Petroleum Technology* (July 1987): 821–34.

109 **Comment** This is not news to the mining community in Nova Scotia. I include these comments only to indicate what is being done in other, geologically similar, areas respecting the control and exploitation of coalbed methane.

110 Gary Ellerbrok, "Lingan Colliery – Methane Extraction and Utilization Project," presentation to the Mining Society of Nova Scotia (Sydney, 1984). Roy MacLean, mining consultant to the Inquiry, suggested that methane drainage at Dominion Coal commenced earlier than this.

> Lingan Colliery, belonging to the Cape Breton Development Corporation, is in the process of constructing a methane extraction system consisting of a network of underground pipelines to the surface and a surface methane extraction plant. Upon reaching the surface, the gas will be prepared for delivery to a consumer.

Two studies completed in 1981 – both reports of the Nova Scotia Demethanation Project – focused on the commercial recovery of coalbed gas in the Pictou coalfield by various drilling techniques.[111] In a summary report on the Demethanation Project, consulting geologist Greg Isenor noted that the project included two wells that produced "sub-economic amounts of gas."[112] Isenor did state that further evaluation of the drilling prospects should be conducted. In an article submitted to the Chamber of Mineral Resources of Nova Scotia, Isenor stated:

> Excellent potential exist[s] in the Cumberland, Pictou and Sydney coal basins of Nova Scotia and throughout Prince Edward Island to commercially extract and utilize coalbed methane. The driving force behind the development of our coalbed methane resources in Atlantic Canada is the lack of the availability of conventional natural gas and the high cost of competing energy sources compared to Western Canada and the United States. It will be only a matter of time before the CBM resources of Atlantic Canada are exploited and utilized.[113]

Interest in the exploitation of methane in the Pictou coalfield was revived in the early 1990s. A joint venture of Nova Scotia Power Corporation (NS Power) and Resource Enterprises Inc. of Salt Lake City, Utah, is exploring the methane potential. According to Bill Hearn, special projects advisor for NS Power, three boreholes were sunk in the Stellarton area.[114] Drilling technology has improved over the years, and the holes are being fractured after drilling to obtain more accurate test results. Hearn said that more drill holes are being considered in the area under lease.[115] Depending on the outcome, the gas could be used to fuel the Trenton generating plant or could be diverted to the natural gas pipeline currently under consideration. The joint venture expects to continue drilling and anticipates results by 1999.[116]

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111 Algas Resources Ltd., "A Coalbed Methane Content Evaluation of the Pictou Coalfield – Pictou Co., Nova Scotia" (1981); A.J.P. Thompson, "A Coalbed Methane Content Evaluation of Selected Coalfields of Nova Scotia" (1981).

112 G.P. Isenor, "The Nova Scotia Demethanation Project Summary Report" (1981).

113 Greg Isenor, "Coalbed Methane," submitted to the Chamber of Mineral Resources (Halifax, October 1993).

114 Telephone conversation, 7 February 1997.

115 The area under lease does not include any of the Westray mine site, including the abandoned underground workings.

116 **Comment** Even if the project determines that gas extraction is not economically viable, it may still be feasible as part of any future coal mining operation. Methane extracted before, during, or after mining could be used to power or heat the mine infrastructure, or it could be sold to NS Power in exchange for electrical power. According to Charles Dixon, Jim Walter Resources can cover its total electric power cost from the sale of methane to Black Warrior Methane Corp. Electric power is a significant overhead cost in underground coal mining.

Although we have discussed mainly gas drainage in advance of mine development, active drainage during mining is common. Devco, at its various mines in Cape Breton, routinely carries out methane drainage. The Devco process is described in its training manual, Duties and Responsibilities of a Mine Examiner/Shotfirer:

> The purpose of the methane drainage system is to extract as much methane from the strata above and below the working seam as possible, and deliver it to safe areas in the return or to the surface. This greatly reduces methane emission into the ventilation system at the face and at the top of the wall.[117]

The manual describes various methods for drilling boreholes and for installing casings, pipes, valves, and so on. The captured methane is released eventually into the atmosphere at the surface. The objective is safety and health, without consideration of any economic side benefits.

A complete methane drainage system was installed in Devco's Lingan mine. The company planned to fire a generator with the methane produced and sell the power to NS Power. However, in early 1993, before the methane drainage system was fully operational, the Lingan mine was abandoned as a result of uncontrollable flooding. There is a suggestion that the drainage plant could process the methane from other Cape Breton collieries such as the Donkin. A methane extraction study of the Donkin colliery has produced optimistic results. Core samples were collected from a horizontal hole drilled to estimate the gas content in virgin coal. A paper on that project, presented to a 1993 symposium on coalbed methane, reported that "[t]he Harbour Seam has the potential for commercial coal natural gas production from in-mine boreholes. The economic return is estimated to be 3 to 4 times the cost of the boreholes and production facilities if a market for the gas is available."[118]

Obviously, degasification methods currently in use can substantially decrease the danger of methane accumulation in an underground coal mine. If pre-mining degasification results in a safer underground working environment, it ought to be seriously considered before any underground coal mining resumes in the Pictou coal basin. If there is an economic benefit to such a program, so much the better. Even if the gas were used on site for heating or power generation, it could result in some, if not total, cost recovery.

Conclusions

Methane is an integral part of coal and coal mining, a by-product of the natural geological and decaying forces that caused the coal to form. My recommendations address issues of monitoring and control, as well as degasification. With respect to the former, the U.S. ventilation

[117] Cape Breton Development Corporation, *Mine Examiner/Shotfirer Training Programme*, Module C/MO 4/1 (1987), p. 33.

[118] M. Mavor et al., "Assessment of Coalbed Methane Resources at the Donkin Mine Site, Cape Breton, Nova Scotia, Canada," Coalbed Methane Symposium (Birmingham, Ala., 1993): 471–81.

requirements, set out in 30 CFR 75, provide an excellent reference point. I have been greatly influenced by their specificity, which I have considered in the context of the terms of reference of this Inquiry as set out in the Order in Council.

In the area of degasification, it may be an advantage to consider both a pre-mining program and a system to operate while mining. My recommendations do not, however, consider any deleterious effect that the release of methane could have on the ambient air or on the earth's ozone layer – aspects well beyond the purview of this Report.

RECOMMENDATIONS

Monitoring and Control

26 **The level of methane in an air intake to the working face of the mine should not exceed 0.5 per cent by volume.**

- (a) **If the methane level exceeds 0.5 per cent by volume, the ventilation technician or other qualified person must take steps to adjust the ventilation system to dilute the methane to acceptable levels.**
- (b) **If the methane level in any part of a mine reaches or exceeds 2 per cent by volume, all workers must be evacuated from the affected area.**
- (c) **The airflow throughout the mine, including the mine face, should be such that methane will be diluted to a level below 0.5 percent by volume, as measured at least 30 cm from the roof or ribs.**
- (d) **The velocity of air throughout the mine should be sufficient to prevent the formation of methane layers.**

27 **Each crew at the working face of a mine should include a person trained in the use of a methanometer. This person should carry, while in the mine, an approved device or devices capable of testing for both methane and oxygen, and capable of testing at the roof and in roof cavities for layering.**

28 **The mine operator should provide suitable testing and calibrating facilities on the mine surface. Methanometers should be tested for accuracy before each shift and calibrated as required.**

29 **If the locked flame safety lamp is used at all, it should be handled only by persons who have received adequate training in its assembly and operation. No lamp should be reignited underground unless the methane content in the ambient air is 0 per cent, as determined by a methanometer.**

30 **If the methane level in the area reaches or exceeds 1 per cent by volume, any electrically operated equipment in use should be shut down, and any shotfiring being carried out should be discontinued.**

- (a) **In addition to other safety devices, any electrical equipment operating at the mine face or in reasonable proximity, as established by the regulator, should be equipped with a device capable of continually monitoring the methane content of the air.**
- (b) **If the methane content exceeds 1 per cent by volume, the methane monitoring device should automatically shut down the electrical equipment.**

(c) The electrical equipment should not be re-energized until a qualified person certifies that the methane content in the air has been diluted to a safe level. (30 CFR sets out this requirement as it applies to mines under the jurisdiction of the U.S. Mine Safety and Health Administration.)

(d) The methane monitors installed on electrical equipment should be kept operative at all times and tested weekly for accuracy. Sensors should be affixed to the equipment as close to the working face as practicable.

31 The operation of mobile diesel-powered equipment underground should be regulated to ensure that the health and safety of the workforce is not endangered or impaired by such operation.

32 The regulator may require, as part of the mine development plan, a plan for the installation of a remote system for monitoring the mine atmosphere, with appropriate audible alarms and recording devices. Such a monitoring plan should include the provision that a qualified person must be at the remote monitoring station at all times that the mine is operating.

Degasification

33 As a prerequisite to the resumption of underground coal mining at Westray or elsewhere in the Pictou coal basin, the province should require the completion of a study into the safety and economic factors involved in drainage of the coalbed methane in the mining area concerned.

34 Every mine development plan should include complete details of any program or process designed to drain methane from the coal seam before, during, and after mining. The regulator could waive this requirement if satisfied that the program or process would be impractical and that general mine safety would not be compromised.