CHAPTER 14

The likely cause of the explosions

Introduction

1. The commission is required to report on the cause of the explosions at Pike River on and after 19 November 2010. Because the mine has not been re-entered, the cause of the first, and subsequent, explosions can be based only on the evidence available without a scene examination.

2. The commission accessed work undertaken by a team of investigators and a panel of experts established by the Department of Labour (DOL).[1] The panel was co-ordinated by David Reece, a Brisbane-based mining consultant with a wealth of experience in mine management, mine inspection and advising the mine industry. The other panel members are Professor David Cliff, an expert in gas analysis and mine explosions, Dr David Bell, a mining geologist, Tim Harvey, a ventilation engineer, and Anthony Reczek, an electrical engineer. In October 2011 the panel provided the department with a report on the nature and cause of the first explosion. In February 2012 the investigation team leader, Brett Murray, and Messrs Reece and Reczek gave evidence at a commission hearing. The commission acknowledges DOL's co-operation in making the main investigation and the expert reports available and also in providing oral evidence.

3. Determination of the cause is complex. As will be seen, the commission is confident that the explosions were caused by the ignition of methane. But to determine why and where they occurred required expert analysis and assumptions. One of the most important estimates the experts had to make was the volume of methane that ignited; this then allowed the circumstances surrounding the explosion to be inferred. Estimates of the amount of methane varied depending on the assumptions adopted.[2]

4. The following discussion about the causes of the explosions is not intended to be definitive. If, and when, the mine is re-entered, any conclusions about the causes of the explosions will need to be re-evaluated.

The cause of the first explosion

Activities in the mine on the day

5. The DOL investigation report contains a close description of the mine workplaces and an intricate analysis of all known events that occurred during the morning shift and into the afternoon shift on 19 November.[3] The following discussion does not replicate this level of detail, but reviews the essential facts.

6. On the afternoon of 19 November there were eight places in the mine where workers were engaged in different activities. These areas are best explained by reference to a mine map drawn to indicate the last-known position of all the men underground at 3:45pm.

The ABM20

7. The ABM20 continuous miner was driving a roadway at the north-west extremity of the mine. An eight-man morning crew cut 3m of new roadway during the shift. Progress was slow because branches of an in-seam borehole were intersected, resulting in methane emissions that caused the continuous miner to trip out. Readings of up to 3.5% methane were recorded in the general body of air, until the gas was dispersed using a typhoon fan and the transected branches of the borehole were plugged.

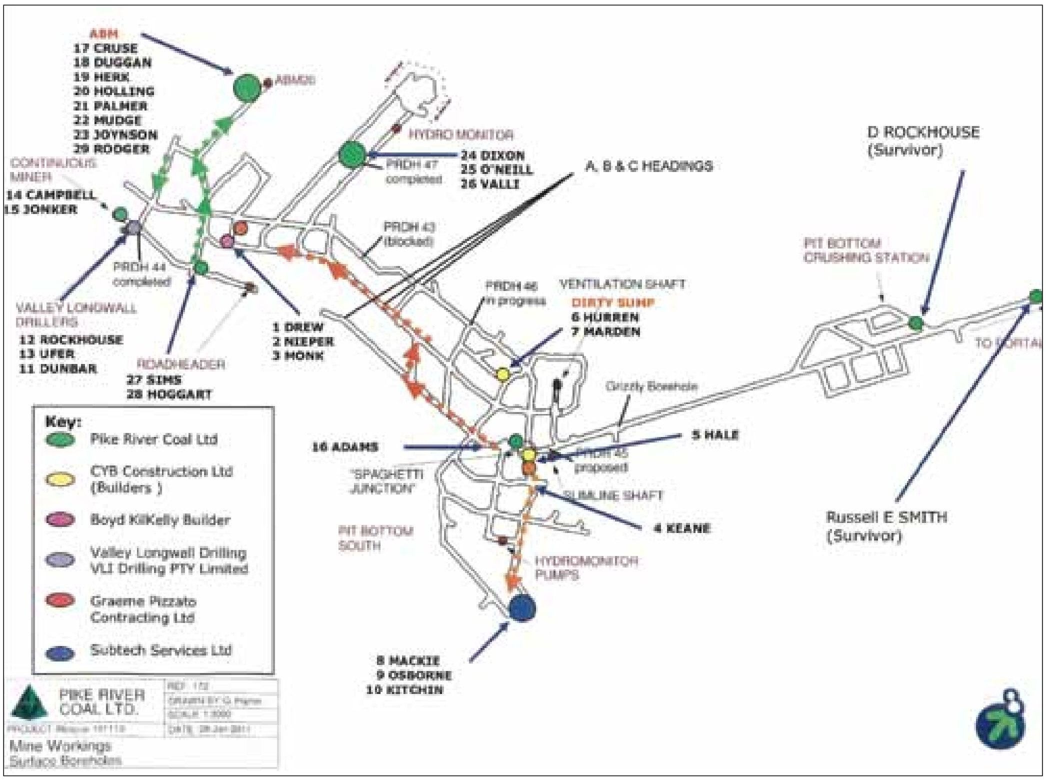

Figure 14.1: Last known position of the 29 deceased and two survivors[4]

The three main roadways running in parallel from pit bottom in a north-westerly direction are known as headings A, B and C from the bottom of the plan, with A heading still incomplete.

8. At 12:20pm mining ceased because fluming water to carry coal from the face was lost owing to a planned shutdown. The afternoon crew reached the face about 2:00pm, and were stocking up the ABM20 and carrying out roadway maintenance while waiting for mining to recommence. Some men may have begun stone dusting or been on a crib break at 3:45pm. Mining could not have resumed because the fluming pumps were still in start-up mode at the time of the explosion.

The roadheader

9. The roadheader was located in A heading, mining in an easterly direction to link up the two branches of this heading. The morning shift experienced some methane layering, although the air readings were steady at 0.8% up to 1:00pm. A fan was operated to control the methane level.

10. The afternoon crew was undermanned, so the roadheader was not scheduled to work until Monday 22 November. Two men moved the roadheader back from the face to ready it for operation after the weekend. It is unclear whether they were still at the roadheader at the moment of the explosion.

Continuous miner CM002

11. This machine was located in a stub at the western end of A heading, but had not been operational for some time and was being serviced on 19 November. Two men, an engineer and a fitter, were working on the machine during the afternoon. Daniel Duggan, the control room operator, was speaking to Malcolm Campbell, the engineer, at the time of the explosion. Gas readings taken at this location during the day were unremarkable.

VLI Drilling Pty Ltd drilling rig

12. This in-seam drilling rig was at drill stub 3 near the western end of A heading. The two-man crew began a day shift at 7:00am. The night shift experienced a malfunction with the drilling rig, as a result of which the connection to 16 drilling rods in the borehole was lost. The day shift endeavoured to reconnect to the rods and retrieve them. Whether they succeeded is not known. An observer, who was to start work the next week, was also with the crew that afternoon.

13. Gas readings, and a measure of the methane flow rate from the borehole taken during the morning, were normal for a drilling rig stub.

Cross-cut 4, B–C headings

14. Three contractors were working a day shift in an inbye cross-cut between B and C headings. They were constructing a board and brattice stopping required for ventilation control. Comparatively little was observed of their progress during the day. By 3:45pm they may have finished work in preparation for catching the 4:00pm taxi out of the mine from Spaghetti Junction.

The hydro-monitor panel

15. The three-man hydro-mining crew began a 12-hour shift at 7:00am. The night shift had experienced a water leak while operating the monitor. However, the day shift used it to cut coal until 12:20pm, when the supply of fluming water to the mine was halted. Little was seen of the crew throughout the day, but they likely used the downtime to undertake maintenance work, including fixing the monitor leak. The three men were probably in the hydro panel at the time of the explosion. Video footage obtained via a drill hole into the hydro panel cross-cut (PRDH47) confirmed the presence of one body in that location.

The dirty water sump heading

16. Two contractors were working in this heading using a bucket excavator, known as a brumby, to excavate an area in readiness for the construction of a concrete sump. This machine did not have a fixed methane detector or an automatic shutdown system, and nor did the men remember to take a portable gas detector with them into the mine. At 3:45pm the men may still have been at work in the heading, or preparing to leave on the 4:00pm taxi.

Pit bottom south

17. Four contractors were working a day shift installing a water pipeline at this location in the southern extremity of the mine. The contractors used a dump loader to cart and dump excavated material at the grizzly. The machine broke down several times during the day and was last seen at Spaghetti Junction where the operator, Riki Keane, was working on it. It is not known whether the other three contractors remained at their workplace at 3:45pm or were en route to catch the taxi.

Four workers in transit

18. An underviewer, Conrad Adams, drove a driftrunner into the mine at 3:15pm and was last seen near Mr Keane's broken-down dump loader. The taxi driver, John Hale, was also in the Spaghetti Junction area ready to take miners and contractors out of the mine at 4:00pm.

19. Daniel Rockhouse was a member of the ABM20 afternoon crew, but at the time of the explosion he was parked at pit bottom in stone, refuelling a vehicle. Russell Smith was late for work and driving inbye up the drift at the time of the explosion.

The fuel consumed in the first explosion

What was the fuel type?

20. An explosion is a violent release of energy resulting from a rapid chemical reaction, which produces a pressure wave, substantial noise, heat and light. An explosion requires an explosive fuel source, oxygen and contact with an ignition source.

21. Methane occurs naturally in coal seams and is released by mining activity. It is explosive in the range of 5–15% methane in air. The coal measures at Pike River had a gas content of approximately 8m^3/tonne of coal. The gas composition of the seam was at least 95% methane, with small quantities of carbon dioxide and ethane.[5] Methane

was the suspected fuel source as soon as the explosion occurred.

22. The other possible fuel type was airborne coal dust, although wet mining conditions at Pike River suggested it was not likely to be the primary fuel source. It could, however, have been a minor contributor to a methane-fuelled explosion.

23. Professor Cliff analysed the results of gas samples obtained from about 9:00pm on 20 November, principally from the top of the fan shaft. The ratio of gases found in these post-explosion samples is 'consistent with methane being the primary cause of the first explosion.'[6]

24. The only potential evidence that implicated coal dust as a contributor to the explosion was some coking located at the exhaust infrastructure at the top of the vent shaft. Samples were sent to the University of New South Wales for analysis, specifically to establish if coking had occurred. If it had, this would indicate the conversion of coal dust into coke as a result of explosion temperatures. Only a very small percentage of coked particles were found, consistent with a minor involvement of coal dust, if any. Coal dust explosions are extremely violent and the first explosion at Pike River was sluggish. The joint investigation expert panel concluded that it was a methane explosion.[7]

What quantity of methane?

25. To determine the source of the methane consumed in the explosion, the panel first assessed the likely volume of methane required to produce an explosion of the kind recorded on the portal closed circuit television (CCTV) footage. This footage was the starting point from which to work back and endeavour to extrapolate the initial methane volume.

26. The blast exited the portal for approximately 52 seconds,[8] with most energy expended in the first 30 seconds. The cross-sectional area of the stone drift at the portal was approximately 22m^2. To estimate the velocity of the blast, the speed at which debris passed through the 7.5m field of vision of the camera was calculated. The camera recorded four frames per second and debris cleared the field of vision in less than one frame. This indicated a blast velocity greater than 30m/s (metres per second) and within a range up to 70m/s.[9]

27. The expert panel's analysis of the blast enabled the volume of gas ejected at the portal to be estimated. Then followed the extrapolation process:

Explosion products ejected at the portal	30–70,000m^3
Double this for a similar volume of products ejected at the vent shaft	60–140,000m^3
Divide by 5 (the assumed expansion factor of the explosion) to establish the volume of mine atmosphere which exploded	12–28,000m^3
Reduce explosive mine atmosphere volume to 5% (the lower limit of the explosive range of methane) to establish the minimum volume of methane consumed in the explosion	600–1400m^3.

28. However, the expert panel concluded that the methane consumed in the explosion was more likely to be at least 1000m^3, and possibly a much higher amount. This reflected the high concentration of carbon monoxide in the post-explosion gases, as confirmed by the two survivors' prolonged loss of consciousness and the analysis of early samples from the vent shaft. High post-explosion concentrations of carbon monoxide indicate a fuel rich explosion.[10]

Some revised thinking

29. In light of points raised in the cross-examination of Mr Reece, and following subsequent discussions between experts, Professor Cliff revised some aspects of his explosion calculations. He discussed these aspects in a transcribed telephone conference on 13 March 2012, to which an expert adviser to the commission, Darren Brady of Queensland's Safety in Mines Testing and Research Station (SIMTARS), contributed.

30. The first change related to the methane content of the first explosion. After discussion and consulting experts from the United States, Professor Cliff (supported by Mr Brady) concluded that it was likely the explosion consumed even more than 1000m^3 of methane. Although the pressure wave at the portal was significantly long, the explosion was not particularly powerful; rather it was slow and weak. It was also described as a 'deflagration' (explosive burn), rather than a 'violent detonation'. This supported a methane rich mixture greater than 10%, and perhaps approaching the upper limit of the explosive range, 15%.[11]

31. The previously adopted expansion factor of five was also revised. Discussion with other experts led Professor Cliff and Mr Brady to conclude that the expansion factor could have been as low as two and was not likely to be as high as five. A lower expansion factor indicated that the volume of the explosive atmosphere in the mine was likely to be larger than previously thought, in order to still produce the gas volume.

32. The combination of the two factors, a higher methane concentration and an increased volume of explosive atmosphere, pointed to an even larger methane volume than the previously favoured 1000m^3. In the course of the discussion, Professor Cliff favoured 2000m^3 of methane as the upper end of the likely range.[12]

Possible sources of the methane

The goaf

33. The expert panel concluded that there were few potential locations within the mine capable of producing the required volume of methane. One possible location was the hydro panel goaf.

34. Hydro mining at Pike River had created an irregular goaf approximately 30m wide, 40m deep and up to 9m high. The void volume was approximately 6000m^3. The goaf was not ventilated. Methane would have continued to bleed from the coal seam into the goaf.[13] It also contained an in-seam borehole drilled to explore the limits of the seam and also pre-drain methane. The borehole had been intersected during hydro mining, and therefore provided an additional potential source of methane.[14] The diagram below illustrates the area of the goaf (top right corner) and the intersecting borehole. The gas drainage lines are marked in red.

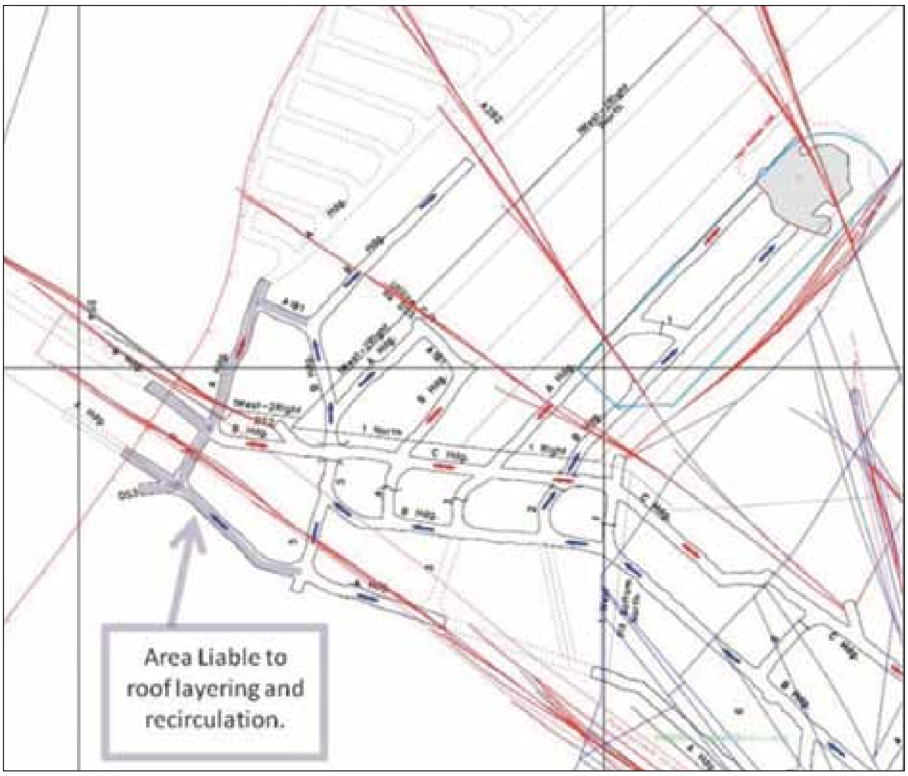

Figure 14.2: The area of the goaf and the intersecting borehole[15]

There was also a rider seam above the goaf which, after disturbance of the roof strata during mining activity, could leach further methane into the goaf.

35. The panel considered that up to 5000m^3 of methane could have built up in the goaf.[16] Methane is buoyant and would not move unless disturbed and flushed out during mining or expelled by a significant roof fall. The goaf was unsupported, so strata failure and roof falls were to be expected. Indeed, the mine had experienced a large goaf fall in October, and a flushing out of methane by the monitor during mining on 17 November. Both events expelled significant volumes of methane into the adjacent roadways.[17]

36. In cross-examination, Mr Reece was asked whether a drillhole into the goaf would confirm the occurrence of a roof collapse large enough to have expelled the required volume of methane, but his answer demonstrated that this is a highly problematic issue.[18]

37. The expert panel favoured the goaf as the most likely source of the methane and a roof fall as the likely expulsion mechanism.[19]

Three explosion scenarios

38. The expert panel suggested three potential ways in which an explosive atmosphere of between 5 and 15% methane in air may have formed to become the fuel source consumed in the explosion. Scenarios one and two implicated the goaf, with methane emitted by a goaf fall as the initiating event, but with different transmission paths outside the hydro panel as the methane was diluted to within the explosive range. The difference between these scenarios was one of degree. The third scenario, however, envisaged a layered accumulation of methane in the western working areas of the mine.

39. Scenarios one and two are best explained by reference to the following diagram.

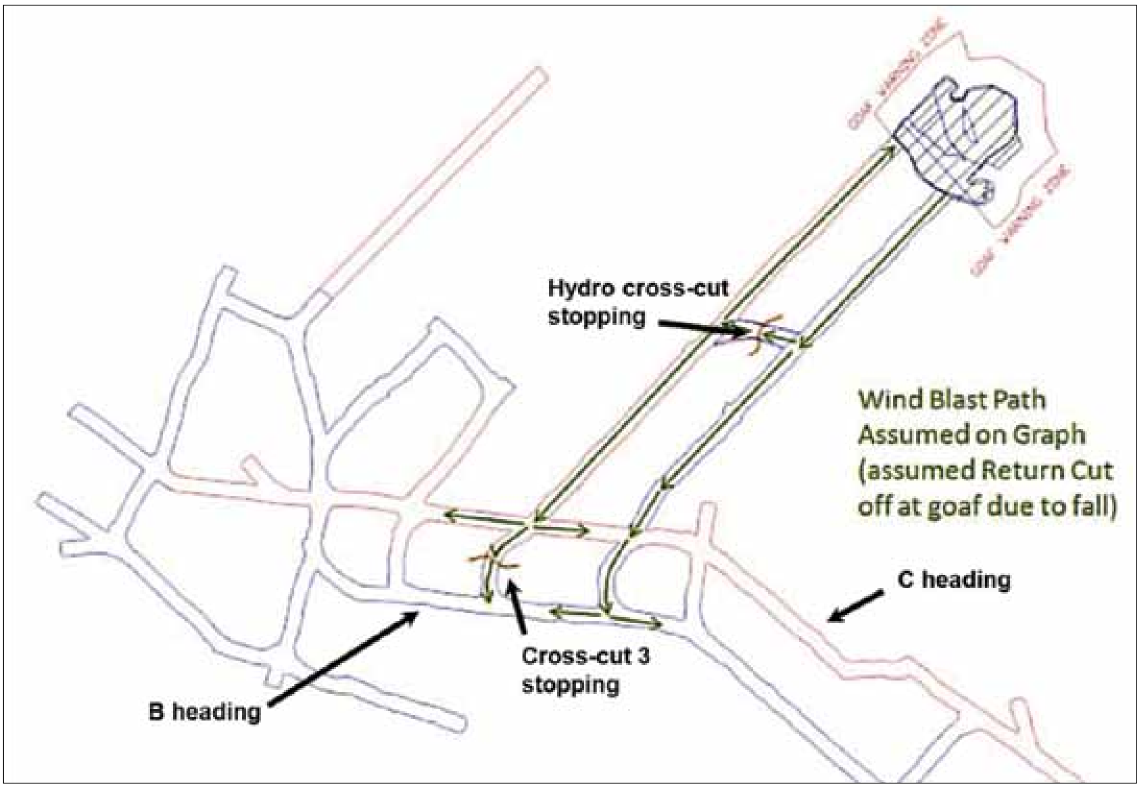

Figure 14.3: Gas flow path due to goaf fall[20]

40. The expert panel assumed that the return roadway from the hydro panel (left side of the diagram) would have been 'cut off at the goaf due to (the roof) fall'. Hence, the diagram depicts only methane expelled along the intake roadway (right side of the diagram) as far as B heading, and then flowing both inbye and outbye. In addition, it was thought that methane would be forced into the hydro panel cross-cut, would breach the stopping in this cross-cut

and travel in both directions along the return (left-hand) roadway. The southern flow was assumed to have crossed heading C, then breached the stopping in cross-cut 3 to reach B heading.

41. The difference between the two scenarios appears to lie in the extent of the methane spread. In scenario one the methane was more localised, while scenario two contemplated a greater spread of methane, including inbye towards the working areas of the mine.[21]

An inbye gas accumulation

42. The third, and 'less likely', scenario was a gas accumulation centred in the most inbye and western area of the mine, where the two continuous miners, the roadheader and the in-seam drilling rig were located. This area is depicted in Figure 14.2 and labelled 'area liable to roof layering and recirculation'. There had previously been ventilation and gas management problems in this area, which triggered the shutdown of machinery and the initiation of various methane control measures. In giving evidence, Mr Reece said scenario three was considered less likely because of the significant volume of methane required, which experienced workers, and statutory officials, should have detected and reacted to.[22]

Difficulties concerning the possible sources of the methane

43. The commission considers that there are some contentious issues relating to the source of the methane.

44. First, the CCTV footage showed that the blast at the portal was variable, being at its strongest for only the first 30 seconds. This variation, however, was not taken into account in calculating the volume of gas emitted. Mr Reece explained that the fall off in the pressure wave could affect the calculation of methane consumed in the explosion.[23] Second, in arriving at the total volume of gas expelled by the explosion it was assumed that equal volumes were emitted from the portal and up the vent shaft. Again, Mr Reece explained that a lesser volume may have been ejected from the vent shaft, given its smaller dimensions and the absence of video evidence at this location.[24]

45. In a working paper dated 16 September 2011 Professor Cliff included a schedule of times recorded on various of the mine's systems in relation to the explosion, including a time reference: '15.45.36–15.46.22, explosion visible at portal for this duration – 47 seconds'.[25] Although only a difference of five seconds, this shortening of the duration of the blast would still reduce the methane volume required to produce the explosion. It is apparent, when viewing the CCTV footage, that assessment of the exact duration of the blast is no easy matter; a value judgement is required.

46. Lastly, Mr Brady pointed out that the standard dimensions of the mine roadways were 5m by 3.5m,[26] although these exact measurements were not consistently achieved. An explosive atmosphere volume of 12,000m^3, for example, would occupy between 686 and 1600m of standard roadway. This represents a significant distance in a small mine, which may suggest that the explosive atmosphere consumed in the explosion was not as voluminous as the panel calculated.

The source of ignition

The amount of energy required

47. Mr Reczek described methane as 'very easily ignited' by an ignition source that is 'intimately engaged', or comes into contact, with the fuel source.[27] The actual energy requirement to ignite methane at its most explosive point (9.8% of methane in air) is 0.29 millijoules. This means that a wristwatch battery has 'many times the amount of energy' required to ignite methane (hence the prohibition on using battery-powered watches underground).[28]

48. The expert panel identified a range of potential ignition sources. The most favoured was an electrical ignition at any one of numerous points in the mine's electrical infrastructure.

A timing coincidence

49. The supply of fluming water to the mine was cut about 12:20pm on 19 November owing to a planned service shutdown at the surface coal preparation plant. Very shortly before 3:45pm the plant advised Daniel Duggan, the control room operator, that the water supply was back on. He switched on the number one fluming pump and made a call to the working faces, using the digital access carrier (DAC) system. Malcolm Campbell, the shift engineer who was repairing a continuous miner at the most western inbye point of the mine, answered the call, but communication to the mine was lost as the two men were speaking. Simultaneously, all telemetric reporting from the mine to the control room also stopped.[29]

50. Data subsequently obtained from the mine electrical system confirmed that the start-up signal from the control room initiated the number one fluming pump start-up sequence at between 3:45:14pm and 3:45:18pm (GPS time). Seconds later, at 3:45:26pm, all power to the mine was lost when circuit breakers at the portal substation tripped.[30] The coincidence of the switching on of the pump followed so soon by an explosion persuaded the expert panel that an electrical cause was the most likely ignition source.

Potential electrical sources

51. The timing coincidence, coupled with some operational problems in the lead-up to 19 November, resulted in a focus on variable speed drives (VSDs) installed in the mine. VSDs enable fixed speed motors to operate at continuously variable speeds. By varying the frequency of the power supply to a motor, VSDs can achieve a softer start-up process with a consequent power saving. And by varying the operating speed of the motor to match its output demand, further savings and improved performance are achievable. VSDs were installed underground at Pike River in conjunction with the main ventilation fan, and pump, motors.

52. However, in varying the frequency of the power supply, VSDs can cause an electrical waveform distortion, termed harmonic distortion. Harmonics are a normal characteristic of a VSD's operation. The distorted waveform can flow back into the power supply grid and into the motor, and from there into the mine earthing system.[31] Harmonics may also flow into metal works, such as a pipeline, that are connected to electrical equipment powered by a VSD.[32]

53. Mr Reczek considered that 'harmonic currents flowing in the earth circuits of the underground power supply would be capable of generating incendive sparking across any mechanical surface connection in the earth circuit'.[33] This incendive sparking, also termed arcing, could 'basically light the entire electrical system up like a Christmas tree' and produce sufficient energy to ignite an explosive methane mixture, should there be one at the point of an arcing.[34] Mr Reczek stated the phenomenon of arcing occurred in many underground coal mines when machines made contact, causing shocks to men who were in contact with mobile machinery and the ground.[35] This risk extended to metal infrastructure connected to a VSD-powered motor, and could, in Mr Reczek's view, have caused arcing anywhere on a pipeline, for example, particularly at a joint.

54. Mr Reczek was supplied with correspondence and other documents relating to the underground electrical installations at Pike River. He considered that technical issues raised in the documents indicated a heightened risk from harmonics.

55. Loadflow studies suggested to Mr Reczek that the main power supply to the mine was insufficient to meet the demands of the underground fans, pumps and other electrical installations. A soft power supply may cause motors to achieve less than their specified output, leading to overheating, 'hot joints' at connections to conductors and drive instability.[36] In these circumstances, VSDs also produce higher currents in an attempt to compensate for the inadequate power supply, and higher currents are a cause of increased harmonics.[37]

56. Documentary evidence confirmed that overheating and instability had affected the main fan and the monitor pump at Pike River.[38] Mr Reczek also highlighted harmonic analysis reports,[39] which showed high levels of waveform distribution and in areas of the mine where this should not have been found.[40]

57. He also relied on photographs that he concluded showed physical evidence of arcing.[41] These depicted pitting caused by arcing to the metal surface of a component of the methane sensor located near to the surface in the vent shaft, but connected to the underground power supply.

58. Before the explosion, the VSD driving the motor of the main fan was replaced because of a circuit breaker problem that caused intermittent tripping of the fan.[42] Other VSDs were also to be replaced by the supplier at a cost of $140,000 because of various failures, including the failure of pre-charge resistors.[43]

59. Although his evidence contained a considerable emphasis on harmonics, Mr Reczek considered that arcing was only a 'potential' ignition source at Pike River. He acknowledged that the lack of access to the VSD units in the mine, limited information about the way electrical equipment was installed and the non-availability of information following the forensic analysis of the failed resistors in the United States all limited the weight that should be placed upon his opinions.[44] Indeed, in another answer, Mr Reczek described his report as 'incomplete' because it involved 'drawing conclusions or inferences, if you like, based on information which is available [but] which isn't conclusive'.[45]

Rockwell Automation (NZ) Ltd

60. This company supplied the Powerflex 700L model VSDs installed at Pike River, and the replacement 700H model for the main fan. The company filed an institutional statement with the commission in which it strongly disputed Mr Reczek's views concerning harmonics. Although Rockwell sought and was given interested party status at an early stage, it did not actively participate in the inquiry until the commission drew its attention to Mr Reczek's witness statement.

61. Rockwell described Mr Reczek's conclusions as 'implausible'.[46] It maintained that he had not taken account of modern VSD technology, which ensures:

> *VSD Input voltage and current waveforms contain very little low frequency harmonics due to active wave shaping of the line current with embedded AC line filters. Modern VSD input voltage and current waveforms meet IEEE [Institute of Electrical and Electronics Engineers] standards which therefore cannot create hot joints and possible resulting methane ignition.*[47]

62. Further, Rockwell conducted a simulation study based on the actual specifications for the number one fluming pump, a 700L model VSD and any associated componentry, including the cabling between the pump motor and the VSD. The essential conclusions reached were that a 700L model VSD generates only low-level harmonic currents, that these are contained in the cabling system and that the energy level of any stray currents going into the earthing system would be insufficient to ignite methane. Rockwell also contended that the overheating of motors at Pike River was caused by defective resistors, and that it was incorrect to attribute the overheating problem to a soft power supply, which could lead to hot joints as a potential ignition source.[48]

63. Since March 2012, when Rockwell filed its institutional report with the commission, there has been ongoing communication between it and the DOL investigation team resulting in a number of outcomes:

- DOL accepts that 'the simulation work in the Rockwell report is detailed and thorough for the cases it considers'.[49]
- However, DOL draws attention to the substitution of a 700H model VSD at Pike to power the main fan,[50] while its investigations have not revealed a sample of the actual cable used at Pike River,[51] but have confirmed the cable termination arrangements used in connecting VSDs to electric motors at the mine.[52] DOL asked Rockwell to undertake further simulation work based on a 700H model VSD, the actual Pike cable termination arrangements and, if possible, cabling of the kind described by Pike's underground electrical co-ordinator.[53] The cable and termination arrangements can affect harmonics.
- Rockwell responded that the scenarios it was requested to simulate were 'speculative', would not be of assistance and it declined to undertake them.[54]

64. There have also been four developments of relevance to the evidence Mr Reczek gave to the commission. He had understood that the number one fluming pump motor was very large, 10 times the size of the main fan motor.[55] This was not the case, meaning that the VSD starting this pump would not have generated a very high level of harmonics. In addition, it is now 'less certain' whether the VSD had actually started, or whether it remained in

start-up mode, at the time of the explosion.[56] If the latter, the scope for harmonic generation is removed, or at least minimised. Thirdly, investigators are now unsure whether there is a 'direct pipework' connection between number one fluming pump and the inbye area of the mine. The number one pump replenished the fluming water supply before another pump in the sequence pumped water inbye. This may eliminate pipework as a connection route, leaving the mine earthing system as the only path for harmonics to travel from pit bottom in stone to an inbye ignition location.[57] Finally, Mr Reczek's view that the power supply to the mine was soft has been contested by Pike's electrical co-ordinator.[58]

65. In June 2012 DOL observed that it had 'not been able to confirm or to rule out' harmonics generated by a VSD as the ignition source of the explosion. Its investigation was described as 'continuing'. When he gave evidence, Mr Reczek acknowledged the constraints he was under. The wisdom of his warning has been borne out by subsequent developments.

Other potential ignition sources

66. In addition to an electrical cause, the expert panel considered a range of different, 'less likely' potential ignition sources. These alternatives included spontaneous combustion, frictional ignitions (from metal on rock, or metal on metal, sparking), a conveyor belt heating or fire, diesel vehicle 'hot surface' ignition and ignition from the introduction of contraband into the mine.

67. Some of these potential sources were discounted for lack of evidence. For example, testing indicated that the Pike River coal seam was not prone to spontaneous combustion and there was no history of its occurrence, and that the conveyor belt was not in service at 3:45pm.

A diesel engine 'hot surface' ignition

68. The expert panel concluded that a fault in the protection system of a diesel engine could not be ruled out as the ignition source. The diesel-powered vehicles and machines used underground at Pike River were fitted with flameproof enclosures designed to prevent an overheated engine from becoming an ignition source. But component failure, incorrect settings and poor maintenance can compromise these safety systems.[59]

69. In addition, throughout Pike River's short history there were instances of the deliberate bypassing of various safety devices designed to counter the risk of methane explosions. Some incidents of this kind were recorded in statutory reports, which were subsequently summarised in a schedule compiled by the commission.[60] The schedule included several instances of interference with vehicle shutdown systems, so that an engine would not cut out in the event of an overheating.

70. This history also influenced the panel in concluding that an engine hot surface ignition remained a potential ignition source.

Contraband

71. Regulations prohibit taking any device or material likely to cause a spark or flame into an underground coal mine.[61] Devices powered by a battery (including wristwatches or cameras) must not be used underground, unless the device is fitted with an intrinsically safe battery system. Matches and cigarette lighters are also banned and smoking is of course prohibited. Aluminium cans are another contraband item, because contact between aluminium and other metals can produce sparking.

72. Again, there had been instances at Pike River of contraband both taken and used underground.[62] In particular, aluminium cans, cigarette butts and unsafe battery-powered devices featured in incident/accident reports that covered the period from August 2008 to October 2010. Although management had taken significant steps to deal with contraband, the expert panel concluded it remained a potential ignition source.

Frictional ignition

73. Although there was no mining activity at the time of the explosion, maintenance and building work was taking place. Machines, including scrapers and diggers, were being used, as were vehicles to transport workers. Frictional ignition from these activities, such as a spark caused by a metal to metal contact, cannot be ruled out. Machinery related sparks had previously been reported.[63]

The main fan

74. The main fan was located underground with its non-flameproofed motor in fresh air in the intake airway and the fan impeller in the return airway. As explained in Chapter 8, 'Ventilation', there had been sparking problems with the fan, and changes had been made, but there was an increased potential for contaminated air to reach the motor.

The site of the ignition

Introduction

75. Pike River was still in a development phase at the time of the explosion. The area of the workings was small, by comparison with a mature mine. Developed mines typically have a number of sections where coal extraction has finished, plus current working sections. Despite the small size of the mine, the information available to the expert panel was limited, meaning it could offer only an indicative conclusion about the likely ignition site.

Some indicative factors

76. The panel concluded that three factors indicated the most likely site: the absence of a reflective explosion wave, the temperature levels experienced by the survivors in the drift and the duration of the explosion wave at the portal.[64]

77. Only one pressure wave was discernible from the CCTV portal footage. Had the explosion occurred close to the inbye western side of the mine, a reflective wave at the portal would have been expected. An initial explosion wave would be transmitted through the workings and down the drift, followed soon after by a reflected wave that had hit and rebounded from the western parts of the mine.[65]

78. An explosion that emanated in the middle of the mine workings, or even outbye of this point, would not be expected to produce a discernible reflective wave. Any such effect would be absorbed or weakened by the web of roadways, intersections and cross-cuts that make up the mine workings.[66]

79. Neither of the survivors, Daniel Rockhouse or Russell Smith, experienced significant ill effects from excessive heat when the pressure wave struck them in the drift. Had the explosions occurred near to the inbye end of the drift, the expert panel expected the hot post-explosion atmosphere would have expanded well along the drift, to the point 800m outbye where Mr Smith was hit by the pressure wave. By contrast, in the panel's view, gases and heat generated by an explosion significantly inbye of the drift would be dissipated and cooled before reaching the survivors, particularly in a wet mine.[67]

80. The third factor was the duration of the explosion pressure wave at the portal. The duration of about 52 seconds was more than twice the duration of the pressure waves generated by the three subsequent explosions, all of which were more likely to have occurred at pit bottom than further inbye. The panel therefore concluded that the longer duration of the first explosion was consistent with a more inbye location, although there were other possible explanations.[68]

Explosion modelling

81. In order to verify that the explosion probably occurred inbye of pit bottom, computational fluid dynamic modelling undertaken by engineering consultant BMT WBM was used to test the panel's assumption. The model replicated the layout of the entire mine, and testing was then conducted using different figures for the volume, and the methane concentration, of the explosive atmosphere consumed in the explosion.[69]

82. Two ignition site locations were chosen: an auxiliary fan next to the intake roadway to the hydro panel and the main fan.[70]

83. The modelling suggested that an explosion located at the main fan was 'less likely', while a location further into the mine appeared 'plausible'. The modelling also indicated that a 10% methane concentration and an explosive atmosphere volume of about 25,000m^3 best matched the explosion footage. These parameters were also considered consistent with the heat exposure experienced by, and the survival of, Messrs Rockhouse and Smith, but less consistent with a blast duration of 52 seconds.

Conclusions concerning the first explosion

84. Based on the evidence available to date, and without a scene examination, the commission finds that:

- methane fuelled the explosion, with no or very little contribution from coal dust;
- the volume of methane consumed in the explosion was substantial;
- the actual volume can only be estimated, but could have been as high as 2000m^3;
- the hydro goaf probably contained approximately 5000m^3 of methane;
- a roof fall in the goaf could have expelled sufficient methane to have fuelled the explosion;
- a layered accumulation of methane in the roof of the western workings of the mine was another possible methane source, either alone or in combination with methane from the goaf;
- the ignition source remains contentious, but a number of possible sources exist, including:
  - an electrical cause, given the timing coincidence between the switching on of the fluming pump and the explosion
  - a diesel engine hot surface ignition
  - contraband taken into the mine
  - frictional ignition from activities that were continuing in the mine
  - sparks from the non-flameproofed underground fan; and
- the possible site of the ignition, and resulting explosion, was in the centre area of the mine workings.

85. Despite the level of uncertainty surrounding several aspects of this exercise, there is no doubt that a large explosive methane atmosphere existed in the mine at the moment of the explosion. This shows that methane control at Pike was not adequate. Ultimately, all explosions are a manifestation of the failure of an organisation's health and safety management system.[71]

The subsequent explosions

Introduction

86. The commission received less detailed evidence concerning the three subsequent explosions, but there was also less conjecture about their nature. Their occurrence was predicted by many of the experts gathered at the mine, who stressed the need to seal the mine to avoid further damaging explosions.

87. There were three subsequent explosions. The second occurred on Wednesday 24 November at 2:37pm, five days after the first explosion. The next explosion was on Friday 26 November at 3:39pm, after a gap of only two days. The fourth explosion was on Sunday 28 November at 1:50pm, also after a two-day gap.

88. The later explosions differed from the first. The second and third explosions had a duration of 30 and 23 seconds at the portal, respectively. Both caused a much more forceful pressure wave than that from the first explosion. Following the pressure wave, air was initially drawn into the drift and then there was a reversal or expulsion of air.[72]

89. The fourth explosion was different again. It caused a billow of black smoke, followed by a fire ball out of the vent shaft and, subsequently, flames that diminished over time, but continued to be visible until 8 December.[73]

Figure 14.4: Fire coming from the ventilation shaft following the fourth explosion[74]

The fuel type and source

90. It is clear that all three explosions were fuelled by methane. A build-up of methane in the workings was expected as soon as the ventilation system was disabled on 19 November.

91. Mr Brady provided a comprehensive overview of gas data gathered at the mine between 20 November 2010 and March 2011.[75] Samples obtained at 4:00pm on 22 and 23 November contained an explosive gas mixture, and there was a methane concentration of over 6% before the explosion on 24 November. The methane concentration rose and fell depending on the time of day, changes Mr Brady considered were related to the natural ventilation flow between the portal and the vent shaft. Predominantly the flow was up the vent shaft, but there were reversals driven by a variable pressure differential that changed according to the temperature and barometric pressure.[76]

92. In the two-day gap before the third explosion there were similar fluctuations in the methane concentration, which climbed to a high of almost 12% at one point. Following the third explosion, few samples were collected owing to damage to the sampling lines and the danger involved in re-establishing them.[77]

93. However, it can be inferred that there was a similar build-up of methane, which ebbed and flowed with ventilation changes, until an ignition source and an explosive fringe coalesced to cause the fourth explosion on 28 November.

The ignition source and the ignition site

94. The most likely ignition source for each of the subsequent explosions was 'hot coal'.[78] Following the heat generated in the first explosion, conditions in the mine were ripe for coal fires or for spontaneous combustion to occur and

provide an ignition source, leading to an explosion once an explosive atmosphere gathered and came into contact with that source.

95. The expert panel concluded that the ignition site of each of the subsequent explosions was probably close to, or a little inbye of, the vent shaft. Logically, there would be an accumulation of methane within the workings and the development of a fringe where oxygen from the natural ventilation circuit mixed with the methane rich atmosphere to reduce it to within the explosive range. When a hot coal ignition source and an explosive atmosphere combined, each of the further explosions occurred.

ENDNOTES

1 This work was part of the joint investigation, but DOL led the explosion analysis aspect.

2 Including (1) the estimated velocities and quantities of gas ejected at the portal; (2) the volume of gas ejected through the ventilation shaft; (3) the percentage of methane (somewhere between 5 and 15%) in the air when ignition occurred; (4) the expansion factor of 5, being how many times the volume of flame was greater than the original explosive mix; (5) the assumed location of the ignition; (6) the dimensions, area and resistance of the mine's roadways; and (7) the path taken through the mine by the explosion.

3 Department of Labour, Pike River Mine Tragedy 19 November, 2010: Investigation Report, [2011], DOL3000130010, pt. 2, sections 3–4.

4 Department of Labour, Last Known Position of Deceased and Two Survivors. Final Version, 28 January 2011 (DOL Investigation Report, Appendix 3), DOL3000130004/2. ('A, B, & C headings' locations added to the map by the commission).

5 Darren Brady, Review of Gas Data Following Pike River Explosion 19th November 2010: For New Zealand Police – Operation Pike, 5 May 2011, SOE.008.00001/14.

6 David Reece, witness statement, 2 February 2012, DOL3000150001/8, paras 29–30.

7 David Reece, transcript, pp. 4454–56.

8 See para. 45 for discussion concerning the accuracy of this time duration.

9 The upper limit of the range was viewed as consistent with the evidence of Russell Smith, who survived the blast 1500m inbye of the portal and suffered significant deafness, but not ear drum damage: David Reece, witness statement, DOL3000150001/10, para. 36.3.

10 David Reece, transcript, pp. 4458–60.

11 Notes from Pike River Discussion, 13 March 2012, MEM0001/8, 11, 17–19.

12 Ibid., MEM0001/9.

13 David Reece, transcript, p. 4467.

14 Ibid., pp. 4467–68.

15 Department of Labour, Investigation Report, DOL3000130010/74.

16 David Reece, witness statement, 2 February 2012, DOL3000150001/11, para. 41.

17 David Reece, transcript, pp. 4465–66.

18 Ibid., pp. 4616–18.

19 David Cliff, David Bell, Tim Harvey, Anthony Reczek and David Reece, Pike River Coal Mine Explosion: Investigation for Nature and Cause (DOL Investigation Report, Appendix 6), October 2011, DOL3000130007/7.

20 David Reece, DR5 – Gas flow Path Due to Goaf Fall, DOL3000150012/1. (Plan modified by the commission)

21 David Reece, witness statement, February 2012, DOL3000150001, paras 20–22.

22 David Reece, transcript, p. 4478.

23 Ibid., p. 4604.

24 Ibid., pp. 4604–05.

25 David Cliff, An Evaluation of Elements Relating to the Cause of the First Explosion at Pike River Coal Mine: Draft, 16 September 2011, DOL3000140009/33.

26 Darren Brady, witness statement, 2 April 2012, SIM0003, para. 2.5.

27 Anthony Reczek, transcript, pp. 4706, 4835.

28 Ibid., pp. 4732–33.

29 Daniel Duggan, transcript, p. 1581.

30 Anthony Reczek, transcript, p. 4733.

31 David Cliff et al., Investigation for Nature and Cause, DOL3000130007/76.

32 Anthony Reczek, transcript, p. 4792.

33 Anthony Reczek, witness statement, 7 February 2012, DOL3000160001/17, para. 60.

34 Anthony Reczek, transcript, p. 4737.

35 Anthony Reczek, witness statement, 7 February 2012, DOL3000160001/14, para. 45.

36 Anthony Reczek, transcript, pp. 4742–45.

37 Ibid., p. 4746.

38 Anthony Reczek, transcript, p. 4731; Rockwell Automation service records, iPower Ltd, Australia Rockwell Automation to Pike River June 2009–October 2010, DOL3000160006.

39 Email, Cosmin Cosma to Mike [no surname], 13 October 2010, DOL3000160012.

40 Anthony Reczek, transcript, p. 4727.

41 AAR10 (photographs), DOL3000160013.

42 Michael Scott, witness statement, 30 May 2012, SCO7770010001/26–27, paras 101–06.

43 Energy NZ Ltd, Department of Labour – Pike River Coal Audit Report for November 19, 2010, 25 January 2012, DOL3000140001/27.

44 Anthony Reczek, transcript, pp. 4765–67.

45 Ibid., p. 4785.

46 Rockwell Automation (NZ) Ltd, Institutional Report of Rockwell Automation (NZ) Ltd in Response to the Statement of Anthony Arthur Reczek for Phase Three (Dated February 7, 2012), 15 March 2012, ROC.001/2, para. 8.

47 Ibid., ROC.001/22, para. 67.

48 Ibid., ROC.001/4, 6–8.

49 Department of Labour, Department of Labour Report on Electrical System Evidence, 8 June 2012, DOL7770050017/4, para. 6.

50 Ibid., DOL7770050017/4, para. 6.1.

51 Ibid., DOL7770050017/8–9, paras 17–23.

52 Ibid., DOL7770050017/9–10, paras 24–30.

53 Rockwell Automation (NZ) Ltd, Memorandum (Second) Regarding the Institutional Report of Rockwell Automation (NZ) Limited and Further Enquiries Received from the Department of Labour, 23 July 2012, ROC. M40001. (Department of Labour letters annexed to memorandum)

54 Ibid., with Rockwell Automation letter annexed.

55 Anthony Reczek, transcript, p. 4737.

56 Department of Labour, Report on Electrical System Evidence, DOL7770050017/7, para. 14.2.

57 Ibid., DOL7770050017/10, para. 33.

58 Michael Scott, witness statement, 30 May 2012, SCO7770010001/39, para. 161.

59 Mine Safety, New South Wales, recently issued a safety warning on the

failure rate of explosion-protected diesel engine systems. A lengthy study indicated that, although reliability had improved, the annual failure rate probability for each system was 23%, meaning it was 90% certain that about six failures per annum coincided with a reportable methane accumulation in a mine: NSW Trade and Investment, Mine Safety Operations Branch, Safety Bulletin: In-Service Failures of Explosion Protected Diesel Engine Systems During 2010 and 2011 (Mine Safety Report No. SB12-01), 19 March 2012, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0007/428614/SB12-01-ExDes-report1.pdf

[60] Royal Commission on the Pike River Coal Mine Tragedy (Katherine Ivory), Summary of the Reports of Certain Incidents and Accidents at the Pike River Coal Mine, November 2011, CAC0114/20–24.

[61] Health and Safety in Employment (Mining – Underground) Regulations 1999, reg 35.

[62] Royal Commission on the Pike River Coal Mine Tragedy, Summary of the Reports, CAC0114/29–30.

[63] Ibid., CAC114/27–28.

[64] David Reece, witness statement, DOL3000150001/27–28, para. 118.

[65] Department of Labour, Investigation Report, DOL3000130010/76, para. 2.49.1.

[66] David Reece, transcript, pp. 4453–54.

[67] Ibid.

[68] David Reece, witness statement, 2 February 2012, DOL3000150001/28, para. 118.5.

[69] Ibid., DOL3000150001/27, para. 117.

[70] Department of Labour, Investigation Report, DOL3000130010/76–77, para. 2.49.3, figure 24.

[71] United Nations, Economic Commission for Europe, Best Practice Guidance for Effective Methane Drainage and Use in Coal Mines (ECE Energy Series No. 31), 2010, p. 3, http://www.unece.org/fileadmin/DAM/energy/se/pdfs/cmm/pub/BestPractGuide_MethDrain_es31.pdf

[72] New Zealand Police, Sequence of Events: Search, Rescue and Recovery, SOE.014.00001/76, 88, 104.

[73] Darren Brady, Review of Gas Data, SOE.008.00001/81.

[74] New Zealand Police, Pike River Coal Mine – Sequence of Events: Search, Rescue and Recovery, SOE.014.00118/64.

[75] Darren Brady, Review of Gas Data, SOE.008.00001.

[76] Ibid., SOE.008.00001/77.

[77] Ibid., SOE.008.00001/81.

[78] David Reece, witness statement, 2 February 2012, DOL3000150001/25, para. 105.