New Zealand Spontaneous Combustion Case Studies

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Summary
All spontaneous combustion events (heatings) have the similarities of generating heat, carbon monoxide and being potential ignition sources. Practical experience demonstrates that heatings are dynamic and can manifest in many different ways. Difficulties may be encountered associated with the rapid development of the heating, gas analysis and interpretation, ability to isolate a heating and ability to eliminate active or latent heatings. All these problems can best be addressed in a proactive manner, by adopting preventative and precautionary measures.

Introduction

This paper presents four case studies of spontaneous combustion events in New Zealand mines. All of the heatings occurred at sites working sub-bituminous coal with a high propensity to spontaneous combustion. Each heating generated potentially hazardous conditions and each heating was ultimately controlled using water, this is the extent of the similarities.

The details of the heatings are provided in the form of the unfolding sequence of events. This is intended to indicate the unpredictability of active heatings.

Case Study No1

Huntly West Mine Fire
17 July 1986

Background

West Mine is situated 6 km West of Huntly in the Waikato region of the North Island. The workings at West mine lie at depths of between 200m and 350m. The deposit is accessed via twin drifts and a single ventilation shaft.

Two coal seams are present, the Renown seam and the Kupakupa seam, the coal is ranked sub bituminous class "B". The Kupakupa seam is the only worked seam. The seam varies in thickness from less than 1m to more than 12m. Coal has been deposited directly onto weathered Greywacke basement. Basement relief has been found to be highly undulating, this has resulted in deposition of the coal in valleys and on ridges. Coal deposited on ridge structures is found to be thin, disturbed and demonstrates tensional stress. All coal at the mine is highly prone to spontaneous combustion. At the time of fire the mine was developing roadways to access reserves for longwall extraction.

Sequence of Events

17 July 1986

0730 On the morning of 17 July 1986 the mine was not in production due to a union dispute.
Three officials went U/G to examine the mine at 7.30 am. The remaining mine officials being on a training course at a neighbouring colliery.
Colliery engineers identified that the surface compressed air pressure was running low at 55 psi (normally 100 psi). The engineers went U/G to try to identify the leak or problem.

0910 A deputy contacts underviewer, reports smoke in the Return at 7 X/C (figure 1). He is advised to locate the other official on that side of the mine and check the return via air door acesses.

0913 The underviewer informs the acting manager who travels to the upcast shaft to check the carbon monoxide (CO), on arrival smells smoke from the evasee. He contacts the underviewer and advises him to call out mines rescue and recall officials to the mine.

0930 First 5 man rescue brigade arrives at the mine, they proceed U/G with instructions to locate and account for all men.

0940 A deputy reports from U/G that the fire is thought to be between 10 and 13 X/C on the return side of air doors. CO level measured using Drager tubes as >700 ppm in the return at 7 X/C. Deputies advised to wait for the arrival of the mines rescue brigade.

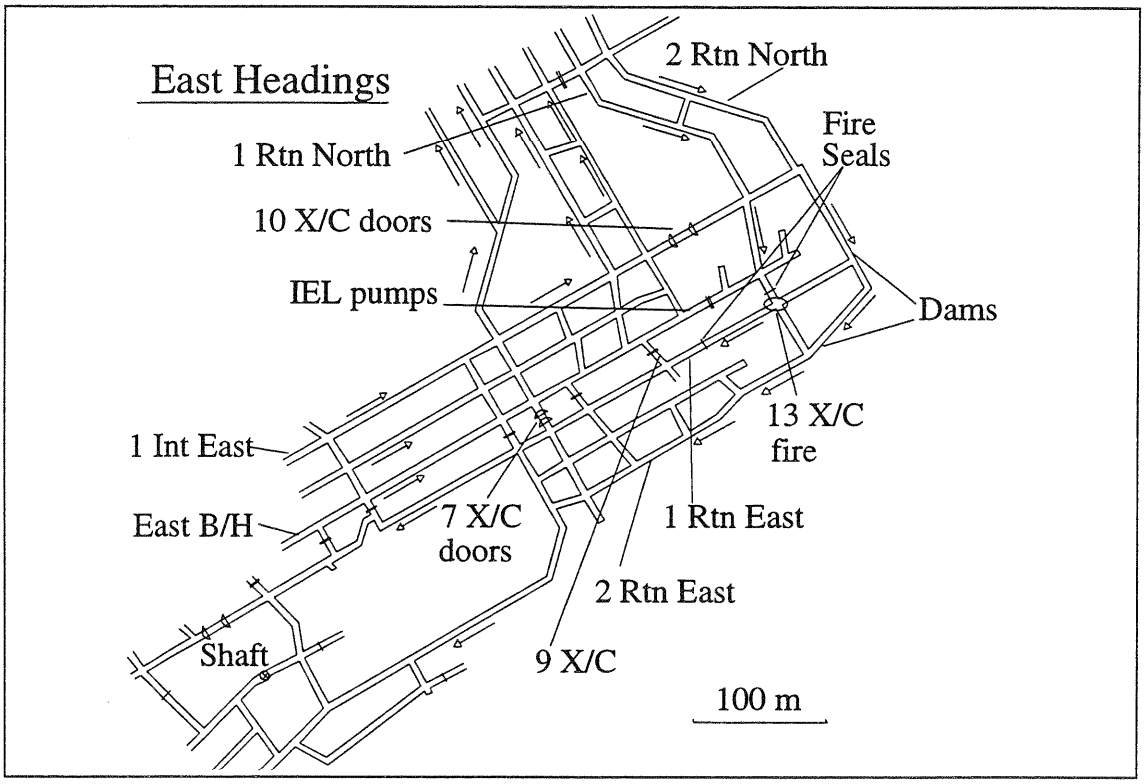

Figure 1. Huntly West Mine East Headings, 1986

0942 Deputy examining South side of mine phones to indicate all in order. He is instructed to wait at pit bottom for the rescue brigade.

0950 Main fan air quantity altered from 70 to 28 m³/s to reduce the airflow over the fire. Brigade meet with deputies, proceed inbye to locate fire.

1005 Engineers phone to surface indicating they were proceeding to pit bottom.
Brigade examines through 10 X/C doors - thick smoke observed. Proceed inbye on main intake to 5 X/C North and examine return airway. North Return airway is clear of smoke to 13 X/C. The conditions experienced were reported as very hot with smoke billowing from the roof along the return roadway back to the 10 X/C air doors.

1020 2nd rescue brigade U/G.

1040 Engineers exit the mine. Brigade set up fire hoses in North Return inbye of 13 X/C, intense heat experienced, the spray from the fire hose partially clears the smoke however this returns when spraying is stopped. Smoke observed to be flowing from the direction of 13 X/C.

1048 Lifelines requested from the surface control to be despatched to brigades U/G.

1058 Surface fan quantity increased to 50 m³/s due to increasing CH4 (figure 2).

1110 Maihak sample point at 13 X/C failed. System had been inoperative during the night and had not detected the onset of the fire.

1120 Brigade members examining of the returns inbye of 7 X/C and at 13 X/C report intense heat and thick smoke (zero visibility) Coal heard to be dribbling at 13 X/C.

1145 Control room instruct U/G to turn off compressed air at 13 X/C as it was considered that the low pressure may be related to a ruptured line feeding the fire.

1150 Rescue brigade at IEL pumps observe thick smoke and intense heat beyond man door leading to the return. Zero visibility at the transfer point. Initially smoke contaminates the north intakes, as spraying of water continues smoke is held in the returns.

1225 Electricians establish telephones at strategic locations. Mines rescue discuss options available the situation is considered dire as access to seat of fire had still not been achieved.
Plan established to approach the fire with high expansion foam. One generator to be established at IEL pumps and one in 13 X/C between 1 Intake East and the East B/H.

1315 Foam generators established and operational.

1345 Foam generation partially reduces smoke and allows access to return side of the fire. 13 X/C observed to have collapsed at the junction of 1 North and 1 East Returns. Coal in the fall and in the roof above the fall is burning.

1450 Intake air supply to the fire isolated from 1 North Return due to foam in roadway. 1 East Return between 13 and 14 X/C was becoming flooded with water. This was encouraged in order to achieve a water seal in a natural depression in the road.
1645 Additional drums of foam ordered from suppliers.
1845 Area inbye of IEL pumps man door reported to be cooling down.
1930 Two rescue brigades U/G building board and brattice seal in 13 X/C between 1 East Return and the East B/H.
2230 Seal being plastered, a hole is maintained in the seal to allow the foam generator to continue throughout the night. A foam generator is established in 1 Return East via a man access made in 9 X/C stopping. A foam generator is set up in 2 Return East.

18 July 1986.
0900 Brigade member collapses due to heat exhaustion whilst constructing the seal in 1 Return East. He is resuscitated and taken out of the mine.
1400 Decision made to construct dams in 14 X/C and 2 Return East to enable the water level to seal two sides of 13 X/C (see figure 1).
2000 Nitrogen range installed to 13 X/C in East B/H.
2300 Dams completed. Brigades men in 1 Return East maintain foam generator. Occasional plugs of high CO gas (>700 ppm) coming through the foam.

19 July 1986
0850 Airway clear of smoke outbye of 13 X/C in 2 Return East. 1 Return East seal completed (see figure 1). Water seal established in 13 X/C between 1 and 2 Return East. Man access sealed in 9 X/C stopping.
1400 Oxygen level inbye 1 Return East seal drops to 4.0%.
1650 Nitrogen injection started through 13 X/C 1 Return North seal at approximately 235 l/s (850 m^3/hour).

20 July 1986
1400 CO falls below 1000 ppm behind the 1 Return East seal.
2000 CO drops to 500 ppm behind the seal.
2200 Drilling equipment established to pump lime into sealed area.

The roadways accessing 13 X/C were pumped full of agricultural lime over the following 2 weeks. Nitrogen injection is continued until 29 September 1986 at a reduced rate of 40 l/s (140 m^3/hour).

Conclusion
The collapse of roof at 13 X/C sometime between 1300 16.7.86 and 0900 17.7.86 probably ruptured a 2" compressed air line. The fire had not been detected during the night by the remote monitoring due to software failure. The leaking compressed air force fed a heating that developed into a major fire. Control of the fire was achieved by six rescue brigades over approximately 48 hours.

During the fire fighting activities intense heat was encountered on roadways accessing the fire, zero visibility was experienced close to and on the return side of the fire. The foam generators were crucial to the control of the fire. Three rescue members were reported to have collapsed during fire fighting activities.

Figure 2. Upcast shaft gas readings

Date	Time	CO ppm	CO_2 %	CH_4 %
17.6.86	1030	700+	0.5	0.81
	1058	700+	0.6	0.86
	1200	700+	0.5	0.74
	1745	600	0.2	0.46
	1845	350	0.18	0.34
	2230	290	0.15	0.38
18.6.86	0900	50	0.10	0.29

Case Study 2
Wairaki No6 Mine heating and ignition
7 September 1991

Background
Wairaki No6 mine is situated in the town of Ohai approximately 70 km North West of Invercargill, in the Southland region of New Zealand. The seam worked is the No2 seam, this is ranked as a sub-bituminous class "A". The coal deposit dips at approximately 7° to the West. The seam is intersected with numerous small faults which are associated with powdery crush zones. These zones are particularly prone to spontaneous combustion.

The Mine, at the time of the incident, was conducting pillar extraction and retreating up dip. A difference of approximately 14 metres in elevation existed between 2 South return and men and materials roads (M&M).

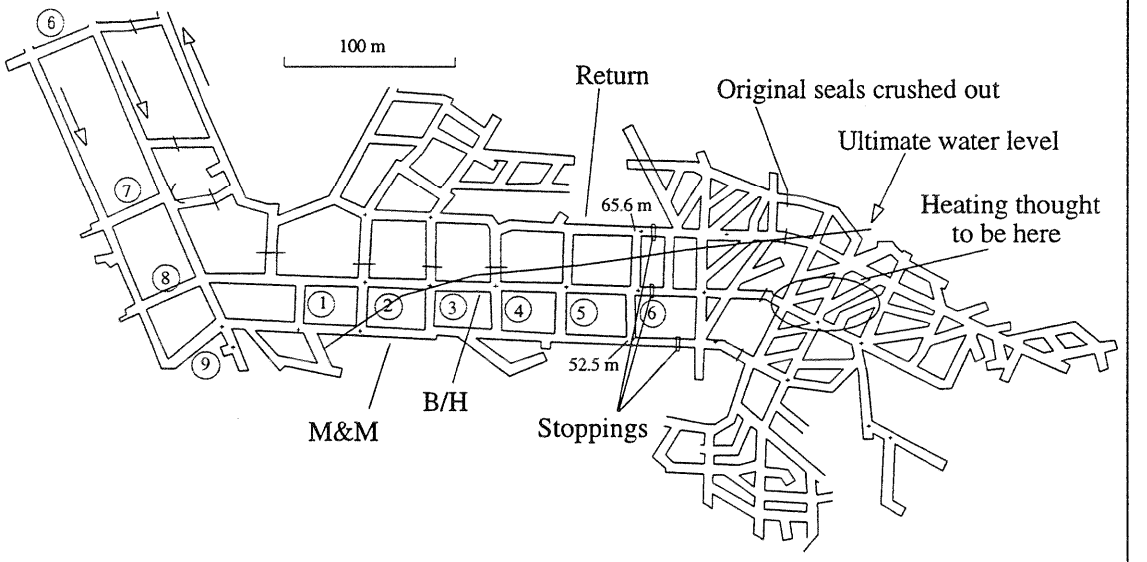

figure 3. Wairaki No6 Mine, 2 South.

Sequence of Events
7 September 1991

0920 Weekend inspection of the 2 South (figure 3) production area identifies a smoke haze in the return. Two men are deployed to erect board and brattice stoppings on the B/H and M&M intake roadways. Return airway CO level measured as 380 ppm (figure 4).

1030 Mine manager and rescue station superintendent don breathing apparatus and examine the goaf area inbye of 6 X/C in 2 South. The general location of the heating was located by the haze/smoke, 100 metres of 25mm hose is run out to deliver water into the area.

1130 The return preparatory stopping site had been previously established, rescue personnel complete the return stopping, working in a CO level of approximately 760 ppm. A distinct firestink smell is noticeable in the return.

1530 Stoppings completed. All men leave out of the mine. Surface fan upcast air CO level is measured as 32 ppm.

8 September 1991

0830 Surface fan examination indicates 65 ppm in the upcast air. A small deviation on the fan chart was evident corresponding to 2120 the previous evening. Mine manager calls out a rescue brigade and proceeds U/G with an official. The B/H seal was found to be completely blown out, the base of the M&M seal damaged. The return stopping was intact.

The pillars in the goaf were heard to be "working" this suggested that the stoppings had been blown out by concussion from a goaf fall. Rescue men replaced the damaged B/H stopping with full board and brattice stoppings, the M&M stopping was patched up and sealed with cement.

figure 4. 2 South return stopping gas readings

Date	Time	CO_2 %	CH_4 %	CO ppm	O_2 %
7.9.91	0930	0.3	0.4	380	
	1530	0.3	0.8	480	
8.9.91	1030	1.0	2.5	1500	15.5
	2030	1.0	1.25	1200	15.5
	2310	1.8	3.2	2000	14
12.9.91	0910	0.5	0.8	600	
13.9.91	0930	0.15	0.4	200	
	1430	0.4	2.3	250	16.5

1310 Stoppings repaired, rescue staff head to the surface.
1340 Surface fan upcast air measured as 12 ppm CO.
1830 Surface fan upcast air measured as 174 ppm CO. A deviation is noted on the fan chart at 1500. Rescue brigade called back to the mine and proceed U/G. M&M stopping found to have the bottom 1 metre blown off, the return stopping was found to have the top 1 metre blown off. The B/H stopping was found to be OK. This damage also appeared to be the result of further concussions caused by roof falls. Repair work is undertaken on the stopping sites.
2015 Gas readings are taken from the return stopping site. Approximately 1 tonne of stone dust is deposited both inbye and outbye of the return stopping site.
2310 Methane level inbye the return stopping measured as 3.2%, CO 2000 ppm. Stoppings completed. Rescue brigade leaves the mine. Surface fan evasse CO measured as 14 ppm.

9 September 1991
0940 An official examines the surface fan evasee to take CO measurement. The reading is greater than maximum range of the Seiger instrument. Mine manager samples the upcast air from the evasee using drager tubes. CO reading 400 ppm. Whilst up the evasee ladder the manager notices one of the fan explosion doors had been displaced by 2 metres. A large displacement was noted on the fan chart as having occurred at 0920.
Because of the elevated and rapid increase in the CO reading at the evasee and the displaced explosion door, it was assumed that an ignition had occurred U/G, probably at the heating site at 2 South.
1200 Unwilling to expose the mine staff or rescue personnel to further danger, the manager decided to flood the 2 South section. The manager and one volunteer entered the mine at midday with breathing apparatus, proceeded to 6 X/C in 2 South and opened the valves on the water and air ranges. Ranges supplying other districts were isolated at 13 X/C. No elevated CO levels were identified on the intakes. The two men exit the mine at 1308. During the examination U/G no obvious signs of damage other than the disturbance to some water barrier bags on the 2 South B/H road.
1500 Water is pumped U/G into the 2 South workings at approximately 800 gpm.

10 September 1991. No personnel allowed U/G. Upcast shaft CO falls to 15 ppm.

11 September 1991
1115 Examination made of 1 South return CO level found to be 4 ppm. Main returns noted to be thick with smoke and at 136 ppm. Surface fan evasee CO measured as 80 ppm. It was assumed that the increase in the CO levels at the evasee was due to gasses being displaced from 2 South goaf upon the collapse of an intake stopping under the weight of water.

12 September 1991
0830 Examination conducted in 2 South return. Smoke still visible, 80 ppm CO in the return, firestink noticeable. Intake roadways flooded to roof level (see figure 3).

13 September 1991
0810 Examination conducted of 2 South return. Atmosphere clear 40 ppm in return. The return stopping was found to have 3 boards blown out from the center. No indication of an explosion, stone dust not disturbed.

16 September 1991 Mine returned to normal work.

Conclusions
The heating in 2 South goaf developed unexpectedly. The stoppings erected to seal the goaf and allow it to naturally inert, blew out on three occasions. The first two occasions were believed to be due to concussions from roof falls. The last occasion resulted in the displacement of one of the surface fan explosion doors and indicated that an ignition had probably been responsible. The only acceptable measure left to secure the mine was to flood the goaf.

The value of preparatory stopping sites as precautionary measures is indicated in this case study.

Case Study 3
Benneydale Mine goaf heating
1995/1996

Background
Benneydale mine is situated approximately 150 km south of Hamilton in the King Country region of the North Island. The mine workings lie under a conservation area. The coal seam is worked from an outcrop via single intake and return adits. The coal is ranked sub-bituminous class "B" and is highly prone to spontaneous combustion. The coal is not gassy and methane is not detected U/G at the mine. The mine was in "care and maintenance" up to the time of the heating. Panel 1 workings had previously created open subsidence fissures to the surface approximately 23m above the seam (October 1989). It was speculated that this may be source of oxygen and associated with the heating activity. First indications of spontaneous combustion activity were reported by the mine deputy as "firestink" from No 9 stopping (figure 5) on the 29.1.95.

Gas samples from No 9 stopping taken before the incident on 23.9.94 indicate 3.2% oxygen present, with no CO. On 7.2.95 the oxygen level behind No 9 stopping was 9.2%. These levels were determined by gas chromatograph analysis.

Sequence of Events
3 February 1995
A site examination was conducted by the ventilation engineer and mine manager. It was established that all of the stoppings (No's 1 to 9) were, despite a rising barometer, on positive pressure - tending to blow gas into the ventilated workings. It was clear that a link to the surface was present behind the stoppings.

The stopping brattice material was observed to be "billowing" apparently in response to opening and closing of the main airdoors at the entrance to the return airway.

14 February 1995
Due to increasing CO levels (figure 6) the decision was taken to conduct a reconnaissance using rescue teams. A re-entry chamber was prepared outbye of No 9 stopping incorporating sample tubes and a valved water pipeline.

15 February 1995
Rescue teams conduct examination of sealed area. Extensive deposits of loose coal found in the open roadways. Oxygen levels typically 8%. One area found to have oxygen level of 15.6% (confirmed by GC analysis). Methane levels of 0.4% are found.

A slight haze was evident in the roadways. The location of the heating was not established. General conditions were cool.

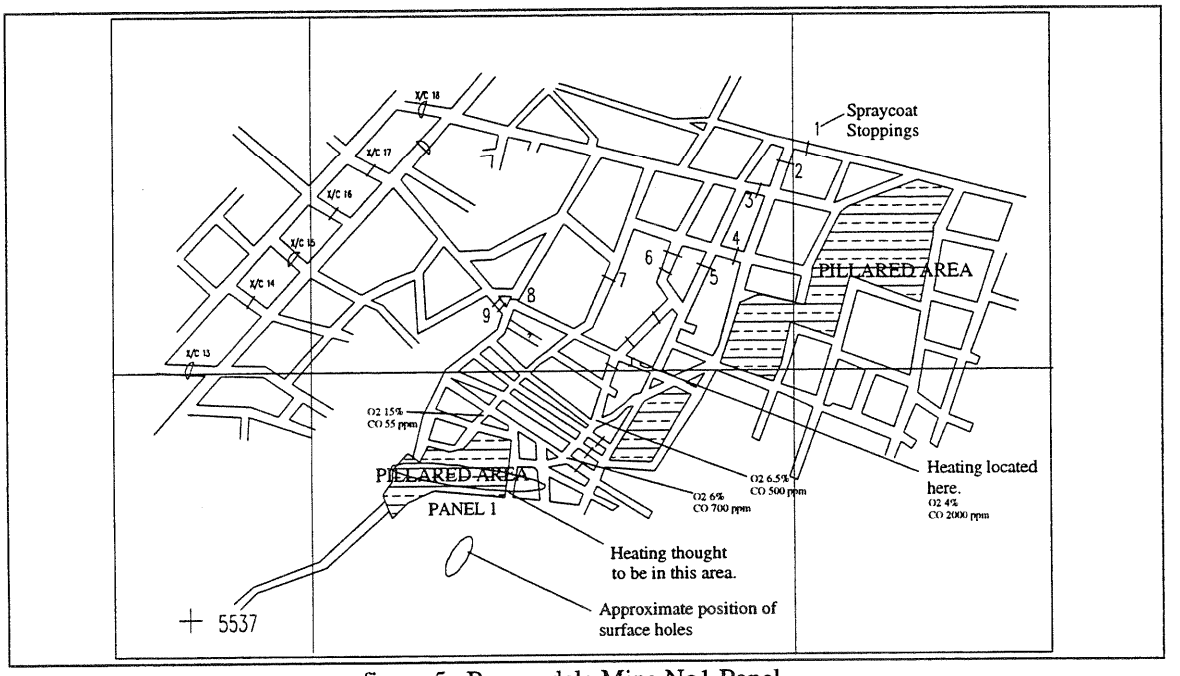

figure 5. Benneydale Mine No1 Panel

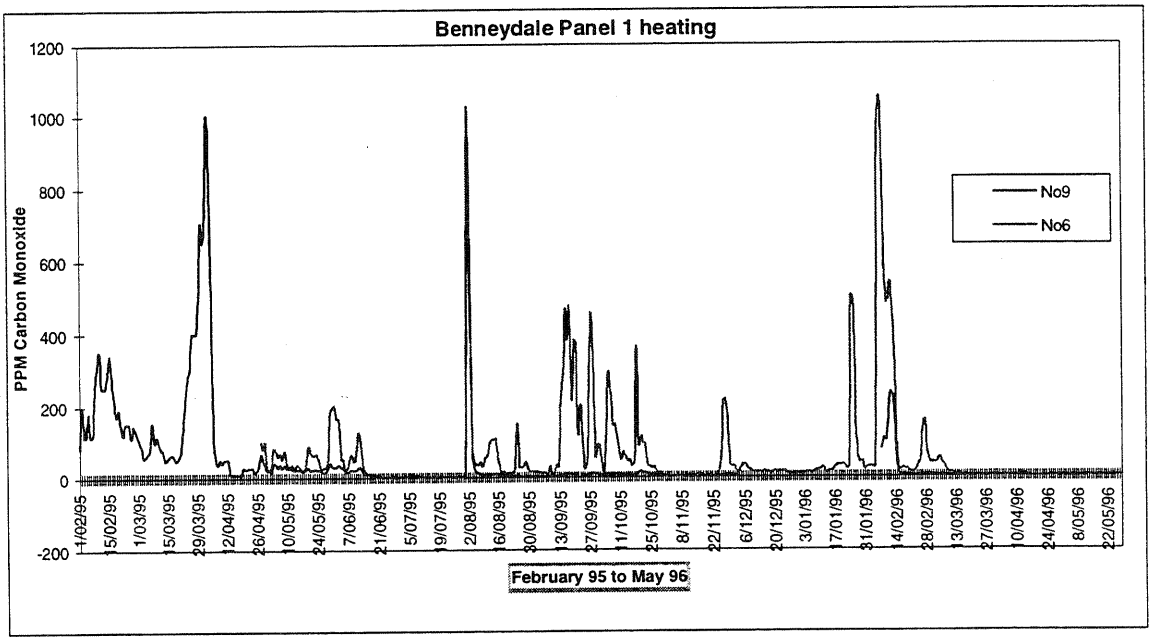

figure 6. CO level Panel 1 Stoppings

Following the reconnaissance recommendations were put forward to:

- examine the surface fissure with respect to effecting a seal;
- to remove the loose coal in the roadways in the sealed area;
- establish a remote monitoring system in the return;
- continue with daily Dräger tube readings.

1 March 1995
Following discussion with a Department of Conservation representative, the vegetation around the surface sinkholes was cleared. No indication of CO or smoke is present at the surface.

6 March 1995
A remote gas monitoring system is established in the fan house to measure CO and O2 at No9 stopping.

21 March 1995
Spraycloth and cement sealant used to seal surface fissure. The degree to which this was successful is not clear. Stoppings underground still indicating positive pressure (typically 10 Pa - the surface fan is operating at 50 Pa).

29 March 1995
Following the rise of CO to 700 ppm at No9 stopping, attempts made to reduce surface leakage by introducing a bentonite mix into the fissures. This appears to have little affect. Options considered to resolve the threat of the heating in the Panel 1 sealed area include, further attempts to seal surface fissure, preparation of balance chambers across all the stoppings and balance to the surface pressure, preparation of U/G dams underground.

2 April 1995
CO level at No 9 stopping increases to 1000 ppm.

3 April 1995
Surface fissure site examined with respect to using earthmoving equipment. This is considered practical, however there could be no certainty that surface sealing would prevent airflow to the U/G sealed area.

4 April 1995
Rescue team reconnaissance conducted of roadways behind No 9 stopping. Heating located, hot coal identified in an area approximately 2 by 2 metres at the goaf edge of a heading. Water delivered to hot coal through 38 mm pipe, flow rate inadequate to wash out or completely quench the hot material.

CO level at heating site 2000 ppm, thick white haze present compounded by steam rising off the hot coal, oxygen level initially reported as 4%. Oxygen rises to 6% whilst water is being played onto heating. Methane level 2.6% (presumed present due to pyrolysis)

Distinct airflow was noted across the heating. This is caused by the convection effect of the heating.

6 April 1995
Rescue team re-enter sealed area and wash out extensive quantities of hot coal from the heating area using the mine flume water supply through a 100 mm range.

A lance is left coupled to the 100mm water supply at the heating site to continue spraying water onto hot coal and surrounding hot sandstone.

1 August 1995
CO level behind the stopping had remained stable at 2 ppm for three months. Re-entry and de-gassing exercise conducted between stoppings 6 and 9 with the objective of flumimg out the heating site. Upon re-entry a slight firestink smell was evident, however no other discernible indications of heating activity at the heating site (warmth, CO, haze,). Within 12 hours of re-ventilation the heating developed into an open fire. The flames are doused with water, the lance re-estasblished to deliver water to the heating and the stoppings re-sealed. Hydrogen is identified in the goaf gas (figure 7).

figure 7. Gas chromatograph analysis during heating activity, stopping No 6.

Date	CO ppm	H_2 ppm	O_2 %	CO_2 %	CH_4 %	N %
2.8.95	924	80	4.3	6.2	0.1	87.26
6.2.96	1438	510	5.4	7.5	0.2	85.6

5 February 1996
Heating flares up in sealed area (figures 6, 7). Mines rescue conduct examination and re-establish water line to heating site. Water delivery pipe to the heating site found to be blocked with fines and hose parted.

12 June 1996
Dam construction started.

23 June 1996
Dams completed.

Conclusions
Several features of this heating are worthy of note. The heating had been inactive for at least three years prior to February 1995. The heating was "awakened" by roadway repair work between stoppings 6 and 9. The heating developed at an oxygen level of approximately 4%. Upon re-ventilating the old roadways between stopping 6 and 9 the heating developed into an open fire within 12 hours. Delivery of water onto the heating successfully controlled the oxidation, however when the water supply failed the heating rapidly escalated.

Case Study 4
Goaf Heating, North 2 Stopping.
June 1995, Huntly East Mine.

Background
Huntly East Mine is situated approximately 3 km East of Huntly in the Waikato region of the North Island. The coal deposit has similar characteristics to Huntly West Mine although the basement relief is not pronounced. Seam thickness varies between 15 and 20 metres. The mine is developing and extracting reserves approximately 3km from the mine portals. Medium term reserves lie West of the 40m Ralph fault, characteristics of this fault had been investigated by roof and floor contacts using an inseam drill. The North 2 roadways were originally driven to provide a mine sump. The roadway closest to the Ralph fault experienced bad ground and two substantial falls occurred. The coal associated with the falls was typically fines rather than slabs. It was considered impractical to pick up the falls due to the roof stability.

Sequence of events
17.5.95 Carbon Monoxide levels in the return from North 2 (figure 8) began to rise slightly around the 17 May. This resulted in the decision being made to seal off the heading.
19.5.96 A brattice temporary seal was erected across the heading. A Maihak sampling point was installed through the stopping to monitor the waste. Sample analysis indicates that the initial CO response is typical for a recently sealed area (figure 10).
5.6.95. Concrete stopping completed outbye the temporary seal. Sample point moved in between the two stoppings.
11.6.95 CO level between the seals starts to rise.
14.6.95 Sample point replaced behind brattice seal. CO level rises above maximum full scale deflection (FSD) of the Maihak analyser.
23.6.95 During the week ending 23.6.95 work begun on sealing roadway sides around concrete stopping prior to pumping water into seal. Three reports of "faint firestink" smell from separate officials. No firestink identified when area examined by mine undermanager or ventilation engineer. Water pumping into stopping begun. Attempts to sample gas from the stopping using stains tubes was unsuccessful due to the slight drawing of air into the sample pipe.
26.6.95 Gas Chromatograph sample taken from behind seal. (analysis delayed until 30 June).
28.6.95 In seam borehole (No 21) identified as being holed through into sealed area - water observed flowing out of the hole through breaks in the coal at corner of roadway outbye stopping.
30.6.95 Gas Chromatograph analysis from the 26th indicates very high CO level (figure 9) and confirms other gas concentrations as identified by maihak. In seam hole grouted to enable pumping to restart.
1.7.95 North 2 stopping sampled for gas chromatograph analysis. Sample taken from maihak analyser outlet due to rising barometer. Analysis indicates substantial reduction in CO level.
2.7.95 Pumping into sealed area restarted at 9.45 am. Maihak CO analyser indicates CO level below 1024 ppm at 1.10 pm.

3.7.95 0445 am CO analyser reading 433 ppm. CO level falls to background norm due to water blockage in the sampling tube inlet.

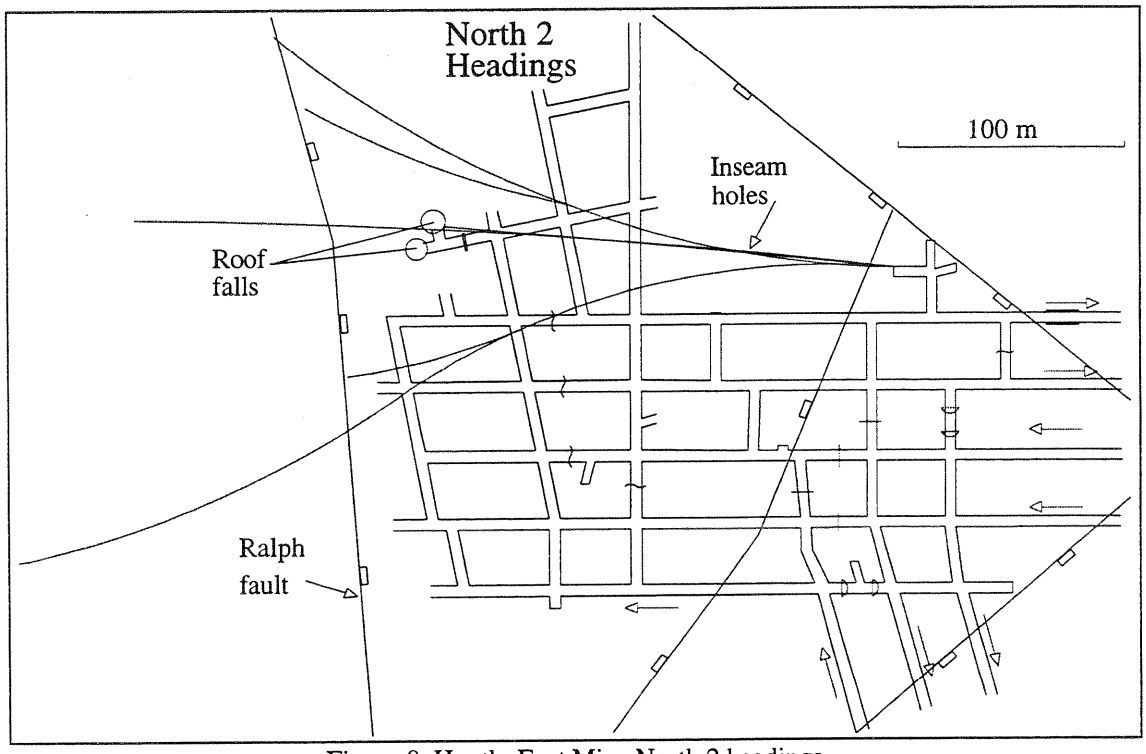

Figure 8. Huntly East Mine North 2 headings

Figure 9. North 2 Stopping Analysis								
Date	19.5.95	6.6.95	7.6.95	14.6.95	14.6.95	26.6.95	26.6.95	1.7.95
Type	Maihak	Maihak	Maihak	Maihak	Maihak	Maihak	G.C.	G.C.
CO	885	360	270	651	FSD	FSD	15,446	1952
O_2	7.5	5.71	10.0	9.19	3.67	0.72	2.4	2.9
CH_4	28.5	41.5	31.0	32.8	44.07	46.95	44.2	65.7
CO_2	1.69	2.12	1.20	1.58	2.56	6.62	6.1	2.8

These figures can be seen in the maihak graphical results attached.

Conclusions

The possibility that a source of oxygen was available to the sealed heading was not initially acknowledged. The construction of an explosion proof stopping to isolate the fall was perceived as the best option to minimize the risk arising if the coal in the fall developed a heating. No intake to return ventilating pressure was present to cause an air flow through the fall. It is considered that the Maihak sample line generated sufficient air movement through the crushed coal to develop an advanced heating. Flooding of the stopping extinguished the heating.

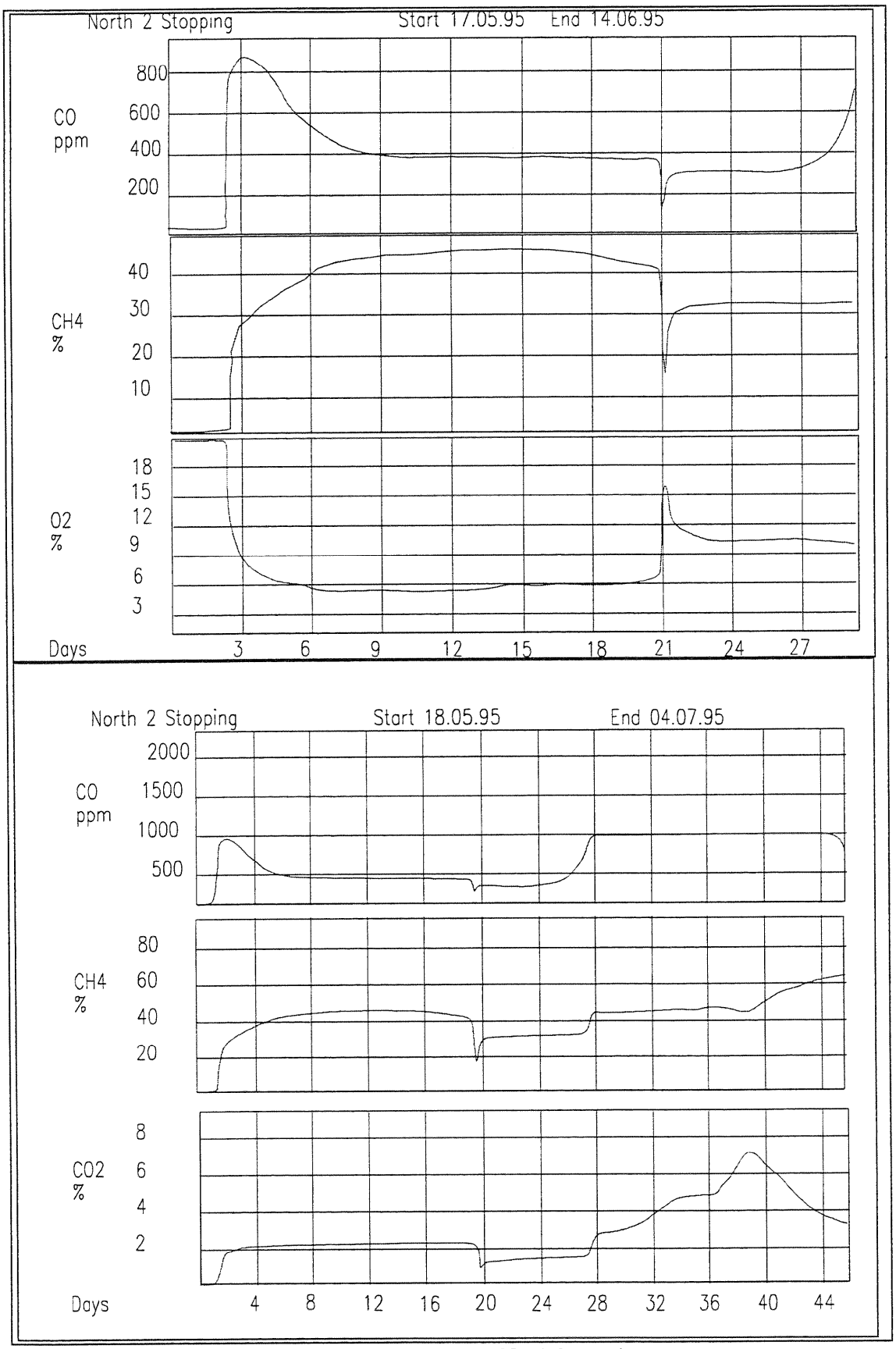

Figure 10. Maihak analysis North 2 stopping

General Conclusions

If it is possible to benefit from the experience of others then the following points should be considered:

- If mine personnel entertain the idea of fighting a major fire U/G then they should be capable of operating a foam generator with their eyes shut.
- Well established preparatory stopping sites may make the difference between exposing personnel to hazardous conditions or not.
- A heating is potentially a problem unless it is dug out or submerged in water. Furthermore assume a goaf heating that has been inertised will re-oxidize very quickly even in low oxygen levels.
- Mine personnel should become familiar with how goaf areas become gassed out. Where possible this should be determined by continuous remote monitoring. If a recently sealed goaf does not behave normally find out why.

In general mine management should consider that the amount of labour and materials that would be required to control a heating is better applied in preventative and precautionary measures.