Ex. 241

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ANALYSIS OF MOURA No. 2 MINE EXPLOSION

7 AUGUST 1994

SUMMARY

Shortly before Sunday midnight, 7 August 1994, an explosion propagating within the 510, 512, and 5 South areas of the Moura No. 2 Mine led to the deaths of 11 miners and put 10 others in "harm's way". Thirty-six hours later, after a second explosion, the mine was sealed.[1]

What might have happened and ancillary factors, based on my understanding of statements given by persons involved and from analyses of data, are discussed below. In summary, these indicated:

1. Mining and ventilation practices exacerbated reactions leading to spontaneous combustion (spon comb or heating) in the 512 Panel (512).

2. The heating[2] could have been recognised in June 1994 during which time it was reversible.

3. Stoppings built to seal 512 neither complied with requirements given in the General Rules for Underground Coal Mines nor could be expected to withstand the forces of even a minor explosion.

4. Many people were underground while a relatively meaningless portion of the atmosphere within the 512 Panel was being monitored.

5. Regardless, the rapid growth of the heating could have been monitored during the early hours of Sunday evening, 7 August, giving management early-enough warning as well as reason to withdraw all persons from the mine prior to the explosion.

6. Management permitted mine officials to be lax in the performance of their duty and in their responsibility for the safety of assigned miners.

7. 512 was the most likely origin of the first explosion.

8. Following that explosion, borehole data support reason to suspect active fires in 510, 512, and 5 South, any of which might have caused the second explosion.

An explosion is the near-perfect criminal; never confessing, seldom sparing an eyewitness, and falsifying when not destroying much of the evidence. Although any analysis must be based mainly on hindsight and is thus suspect, its analysis is the only means at hand to instill vigilence in miners and mine officials who suffer safety myopia.

[1]Times at which events occurred as indicated by MAIHAK data (no tube-travel time compensation) were:

Action	Sampling point No. 5		No. 16
Belt entry sealed	06/08/94	23:42:05	no indication
512 Panel sealed	07/08/94	no indication	02:24:02
Explosion	07/08/94	23:49:57	23:42:27
Explosion	09/08/94	12:21:03	12:58:50

[2]The use of the singular is not intended to refer to or imply one heating at one site; spon-comb reactions might have been ongoing at several sites.

512-MINING and VENTILATION PRACTICES

Figure 1 shows the 512 workings as they were on ~12 July 1994.[3] Not shown are rib sloughs, bottom heaves, and roof falls. The Panel was five-into-six entries-wide (160+ m.) and 13-crosscuts-deep (~440 m.). It dipped ~7° from the junction of the Nos. 1 entries in 512 and 510 (the submains) to the 13th. crosscut (XC) in the No. 5 Entry. The No. 1 Entry, at the highest elevation, was the principal return; No. 2 was the main intake and transport road; No. 3 was a nonisolated belt road on intake air; Nos. 4A and B also were on intake air; and No. 5 was the "bleeder return" despite being on the antibleeder (lowest) side.

Initially, entries and crosscuts were driven ~8-3/4-meters-wide, ~2-1/2-meters-high. In the subsequent retreat, "punched" lifts were taken from the solid inbye 13 XC and along the No. 5 Entry, pillars were irregularly slabbed between every other crossuct, and, where feasible, bottom coal was ramped-mined full height (~4-1/2 m.). Where roof did not cave, and caving reportedly[4] was negligible through much of the goaf, experienced miners should anticipate the ~15 to 40-meter-spans would exacerbate rib sloughing, fender crushing, and bottom heaving.

Ventilation.-- As retreat progressed, stoppings between the Nos. 4 and 5 entries from the 13th. to the 6th. XC were removed. Additionally, the regulator (R) controlling air flows through the No. 5 Entry was opened and closed and opened again as were doors in stoppings separating the No. 1 Entry from the goaf. Also, a hole was cut in the 12 XC-stopping between the Nos. 1 and 2 entries; and, openings were made in stoppings between the 12th. and 13th. crosscuts. Analyses[5] indicated the likelihood of more openings or leakage paths through many of the other stoppings.

These things purportedly were done to stop methane-laden air from backing out of the goaf through the No. 2 Entry into the active workings;[6] to increase air velocities around the large pillars; and, to provide more air to the continuous miner and roof bolter.[7] Instead, the most likely effect was reduced air flows and pressures through the goaf and into the back of 512.[8] Further, this goaf being at a lower elevation than the active faces and main return would tend to cause the rising flows of methane and warmed air to "suck" in fugitive air as well as form layers.

In summary, air flows into and through the goaf were sluggish and erratic. Spon comb is initiated and exacerbated by such flows.

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[3]Based on BHP Australia Coal Pty Drawing No: 45/26. Mid-July, in my opinion, was a critical period in the history of spon comb in 512.
[4]Several persons testified about walking into 13 XC and through parts of the goaf in what had been the Nos. 1, 2, and 3 entries.
[5]This refers to ventilation network analyses I made, which analyses are available to interested persons.
[6]Whether the backing-out was an actual reversal or layering is not clear. For the reported conditions (i.e., area ~22 m^2, velocity ~ 0.6 m/sec, CH_4 ~1.8%) the layering index ~1, whereas to militate against layering required an index ≥2 and a velocity >2.4 m/sec.
[7]On 12/07/94, ~42 and 8.5 m^3/sec of air were measured at sampling points 16 and 5, more than enough to assure positive flows within 512 provided leakages through stoppings were not excessive and flows through the goaf were not restricted by extensive, large falls of roof, sloughed ribs, and heaved bottoms.
[8]Analyses indicated the most likely sites for the fugitive air flows that can lead to spon comb were in areas adjoining the inbye ribs of the large pillars between the Nos. 4 and 5 entries, and between the 9th and 10th XC in the Nos. 1 and 2 entries. Looking at Figure 1, any slabbed pillar would be a good candidate-site.

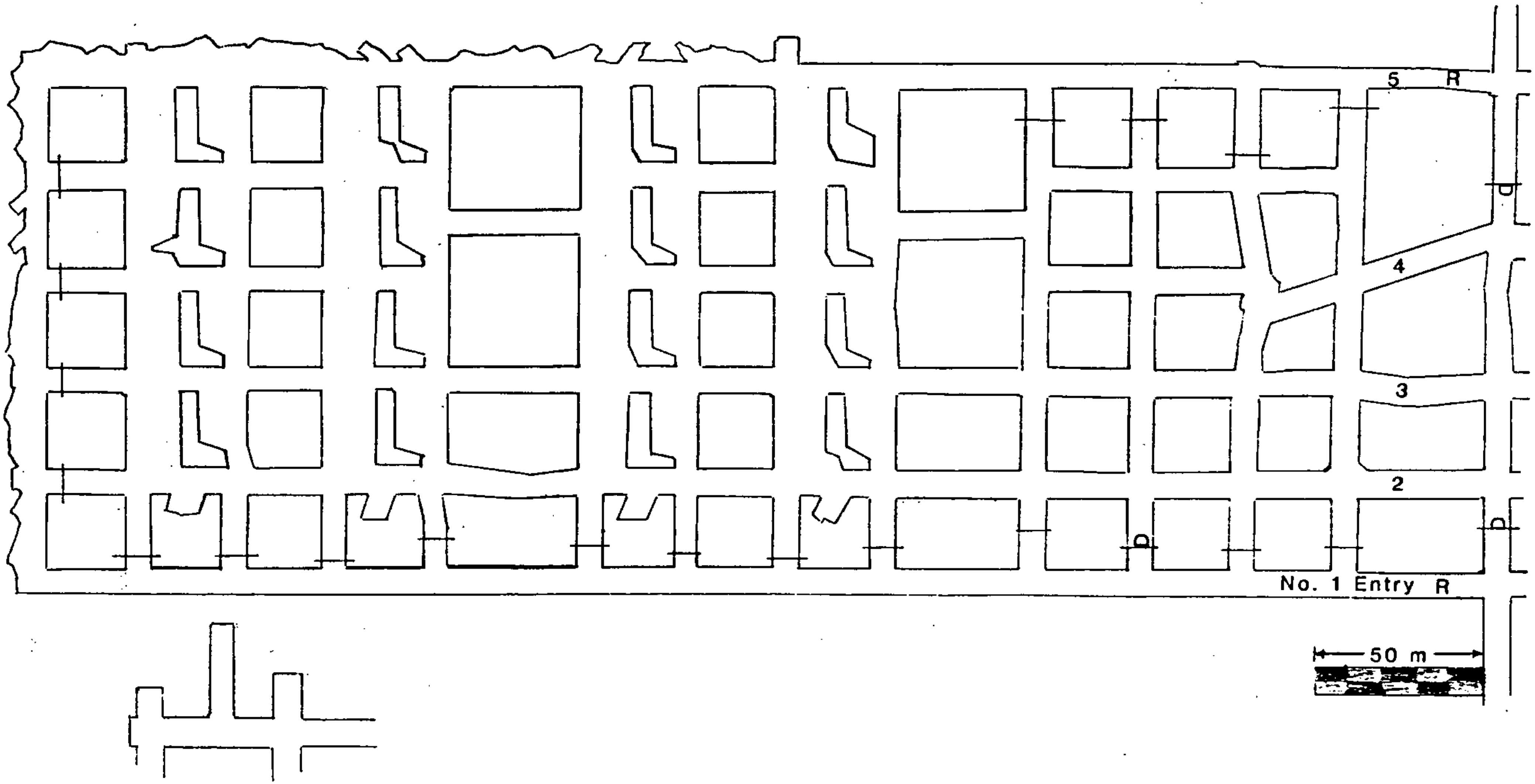

Figure 1.-- MOURA No. 2 MINE 512 PANEL, ~12 JULY 1994

SPON COMB

The common signatures of spon comb, a sweet musty odour, haze, and "sweaty" crowns and roof-bolt plates, are often sensed long before carbon monoxide (CO) gives warning.[9] Some of us, however, are not sensitive to these tell-tales. A chew of tobacco, a pinch of snuff, a stuffy nose lessens our ability to smell; and, to become aware of haze and "sweat" two or more meters overhead in the beam from a cap lamp is debatable. Testimony given before the Enquiry evidenced such a wide range of sensibilities that dependence on these "signatures" is questionable and possibly impractical.

Some statements given by Mouramen discussed "incubation time", some emphasised ppm of CO; while others talked about CO Make. What does all that mean?

Incubation-- Incubation time depends on the type and quantity of coal, its size distribution, its inherent oxygen, fusain, moisture, and epigenetic sulphur, its cleavage and fracture-plane patterns, how well the coal is sheltered, pressure differentials, temperatures of the air and coal, wetting and drying cycles -- to mention but a few of the unpredictable, inconsistent, yet critical factors.

CO and CO Make.-- Dependence on ppm of CO or CO Make also can lead to confusing, if not meaningless numbers. Either increases with increase in temperature of the coal. Without an increase in temperature, however, either increases with increase in quantity of coal being reacted. One equals FIRE, the other doesn't add up to "a hill of beans". The effects of dilution quantities and paths can be equally confusing; as these change, and they do, ppm will rise or fall.[10]

Consider, for example, the data obtained during the 12 July 1994 ventilation survey. At Station 16, in the vicinity of the regulator (R) in the No. 1 Entry, the Ventilation Officer reported 6 ppm CO, 41.87 m^3/sec of air, and a CO Make of 15 liters/minute. The CO-liberation rate from coals like those in Moura No. 2 Mine typically exceeds 30 liters/kg when flames erupt. To liberate ~15 liters/minute, therefore, might indicate:

~1/2 kg. of coal actively burning each minute (~14,000 Btu/min. -- a **HOT** fire), or
~1 kg. of coal giving off a moisture-forming haze (>100° C.), or
~1-1/2 kg. of coal giving off a tarry-like smell[11] (~>75° C.), or
~2 kg. of coal giving off a sweet, musty odour (~>40° C.) or
many kilograms of coal being oxidised with minimal rise in temperatures.

The rate of increase in the 512-CO Make was the fastest in the history of this mine. It was almost twice the rate experienced in 5 North +40, and almost three times that in 5 North -40. Rates in 401,402, 403, and 511 were relatively like that of the tortoise.[12]

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[9] Where haze is observed, the suspect atmosphere should be tested for oxides of nitrogen; these products of diesels are alien to spon comb sources in coal mines.

[10] In one mine, the CO rose from 1/4 to 4 ppm in 8 hours; two hours later the mine was lost. The heating, "hidden" in a pillar between an intake and return, eventually caused the pillar to collapse and flames to erupt. In another mine where CO readings ranged up to 500 ppm, intensive investigations over several years found the CO was from normal oxidation with no serious generation of heat.

[11] Acids, acroleins, and aldehydes in coals give off sweet, musty, tarry odours at relatively low temperatures.

[12] Based on Figure 1 (BHP Australia) in the January 1995 report, Study of the Moura No. 2 Incident of 7-9 August, 1994, by Robert W. van Dolah, Ph.D.

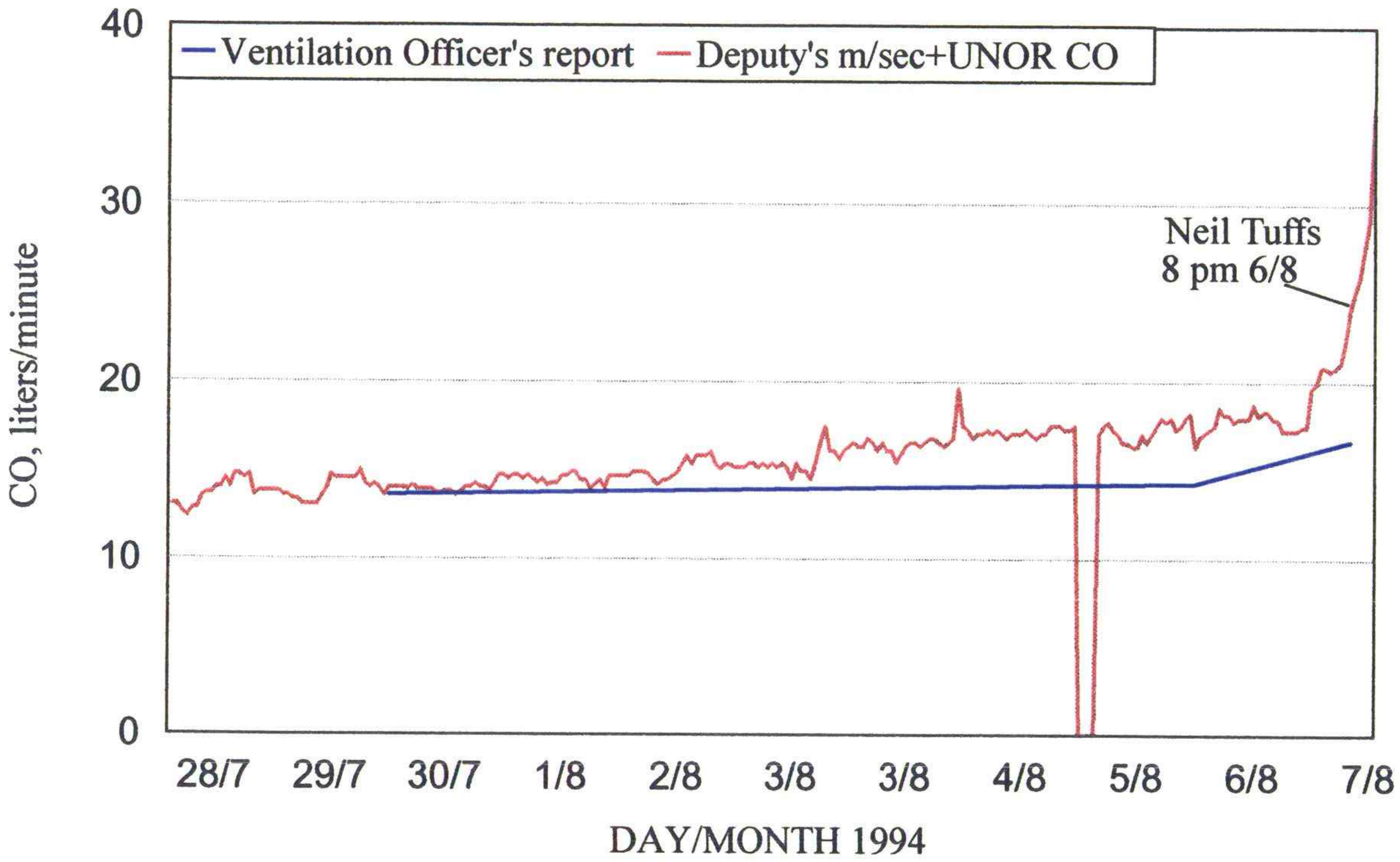

Figure 2. -- - MOURA No. 2 MINE
CO MAKE 3 pm 27 JULY - 1:30 am 7 AUGUST 1994

dwm 4/12/94

Any sustained rise in CO Make, no matter how rapid or slow, is cause for concern. The depth of concern should depend on experience;[13] for example, in a mine having a heating in the past, an increase in CO, no matter how slight, warns it can happen again. The CO Make, from 28 July through 7 August 1994, at Ventilation Station 16 was shown in Figure 2. The red-colored line was based on the air velocities measured at that station on almost every shift during that period and the ppm CO recorded by the Maihak Mine Monitoring System[14] during the shift This red-colored line shows a steady increase during the first week in August with a rapid rise coincident with sealing operations, a period during which air was entering into and flowing out from 512. These data leave no question that mine management had early-enough warning as well as reason to withdraw all persons from the mine.[15] The blue-colored line was based on the Ventilation Officer's calculation of the weekly average ppm CO and a selected air quantity, which sometimes was the lowest[16].

<u>CO/CO_2 Ratio</u>.-- In coals, as it is in your lungs, breathing in (absorption of) oxygen produces carbon dioxide (CO_2) and temperatures far below boiling. Subsequent reactions between CO_2 and carbon in the coal accelerate temperatures and produce CO. Below 150° C. the reaction can be reversed; however, should temperatures exceed 150° C., the rise becomes so rapid little can be done to prevent flaming.

Being the first major gas, other than methane, liberated during the oxidation of coal, CO_2 should be "seen" before CO. Its subsequent rate of rise, however, is not as rapid as is the CO rate. The increase in their ratio, therefore, is positive evidence of an increase in temperature.[17]

Individually, the ppm of either CO or CO_2 is affected by dilution. Their ratio, however, is not except where a large pool of water is between the heating and monitoring point. CO_2 being soluble in water, its measured concentration might be less than correct leading to a higher than true ratio and a false alarm. In contrast, acid water reacting with carbonates, such as rock dust, produces CO_2; this can lead to a lower than true ratio and a false sense of security. Thus, to use this ratio we must have reasonable knowledge of water conditions.People who testified about their travels in the goaf indicated it was free of important pools of water. Regardless, one should expect water to pool in low elevations such as between 12 to 13 XC in the Nos. 4 and 5 entries.

Figure 3 details the CO/CO_2 ratios at sampling points 5 and 16. The ratio at 5 (the blue line) had a sharp rise and an abrupt fall during the middle of June.[18] That was not true at sampling point 16 (red line). A positive, strong rise is shown from the middle of June through the middle of July.

[13]13 September 1991, in 5 North of the Moura No. 2 Mine, the Manager reported the CO Make increased to 6 l/min in the top return and 3 in the bottom. On the 16th, sealing was begun because the Make had risen to 12 l/min. The mine was evacuated on the 19th. purportedly because of concern for frictional ignitions by falls of roof.

[14]The zero readings on 4 August were from a 4-hour period during which no CO-data were recorded.

[15]The Maihak system could have been programmed to show a graph such as that in Figure 2.

[16]Management should have challenged air velocity readings; for example, after many shifts @ ~1.8 m/sec., two were ~1.6, followed by 1.8 and higher. The blue-line calculation on 5/8 was based on 1.55 m/sec.

[17]Amongst the best sources for information on the liberation of gases from the oxidation of coals is the work of Chamberlain, Hall, and Thirlaway at the Bretby (England) laboratory of the National Coal Board.

[18]The erraticalness of Sampling Point 5 data as compared to that at 16 is typical of what happens when major changes are made to ventilation controls.

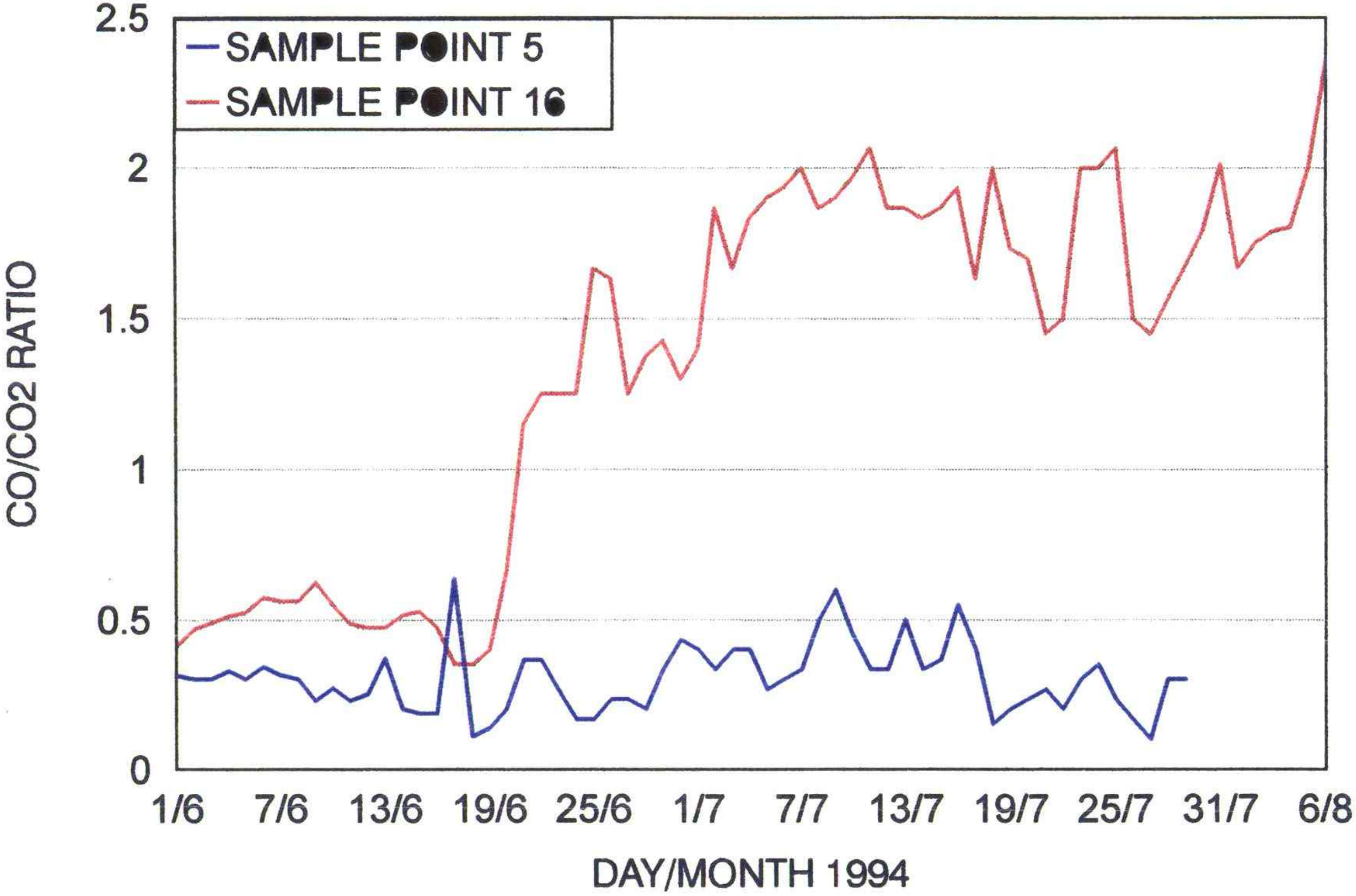

Figure 3. -- MOURA No. 2 MINE
CO/CO_2 RATIO 1 JUNE - 7 AUGUST 1994

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These data give reason to believe a heating was active and growing in 512 prior to 20 June. This places probable sites inbye 9 XC. The subsequent levelling of the curves is typical of what one finds where excessive leakage and other ventilation inadequacies cause a heating to be "hidden" from the main ventilating-air network. This can be expected to result in osmosis rather than ventilation being the means for oxides of carbon as well as other "fire" gases to flow from the heating into the main airstream.

Spon-comb mitigation.-- Monitoring is the canary, the early warning of a possible heating. For this, the miner's best bet is to monitor the CO/CO_2 ratio. Although the majority of heatings begin during retreat mining, monitoring from the start of a panel to its end provides the history management must have to make proper and timely decisions. To develop that history, samples should be taken weekly and analysed by a gas chromatograph[19] or equally good means. The need is to monitor air velocities, barometric and fan pressures, and the relative rates of change amongst the "key" gases, N_2, O_2, CH_4, CO, and CO_2.[20]

Procedures must be consistent and representative. In 512 , for example, samples were needed at least four points:

- Two in the No. 1 Entry. One inbye its junction with 510 but outbye the place in which a seal might be constructed; the second just outbye the last open crosscut (being moved inbye as the place advanced and remaining stationary during retreat operations)..

- Two in the No. 5 Entry like those in No. 1.

The other key to mitigation is preventing air from flowing through large piles of fine coal in partially sheltered places (sloughed ribs, crushed fenders, under falls, heaved bottoms).[21] This, of course, must not be done where methane might accumulate. There, a two-pronged defence is essential. One prong is to mine cleanly, leaving either stable pillars or little to no coal in fenders, stumps, and ramps. The other prong militates against sluggish flows of air -- the velocity of airflows into and pressure differentials across the goaf must be great enough to remove heat as fast as it is produced. To do this, only caved roof should restrict air flows through the goaf into the back bleeder, and leakages or losses into the return) must be the least possible.

Adjustments made to stoppings and ventilation controls in 512 exacerbated spon comb.[22] From the beginning of retreat operations, at least one stopping between 12 and 13 XC should have been kept open. Miners should have neither opened nor removed stoppings adjoining the

[19] Testimony given before the Enquiry implied gas chromatography (GC) was not suitable for samples containing <10 ppm CO or <100 ppm H_2. The speakers erred. CO in ppb can be analysed using a GC-flame ionization detector; H_2 can be analysed using argon rather than a helium carrier, a ruthenium catalyst (Galmac), or an MTI instrument, among the many ways.

[20] Spon comb reactions require consumption of O_2 as evidenced by a decreasing rate of O_2 and increasing rates of CO and CO_2. Consumption of O_2 is marked by a near zero or a rising trend in N_2. Should N_2 decrease check for dilution by CH_4; should N_2 and CO_2 increase with no important change in CO suspect blackdamp.

[21] Creating a zero-pressure differential across a heating is the fastest, safest, and most effective way to stop its progression.

[22] The probable site of a major heating in 512 was between 11 and 12 XC. Testimony given before the Enquiry described the bottoms being softest inbye 11 XC, and much loose coal in those ramps. The rise in CO Make, establishing a trend that remained reasonably constant up to sealing, was evident during extraction of intervening pillars as early as June. This is consistent with observations made by Caddell and Morieson who also told of major changes being made to ventilation controls on or about 17 June.

Nos. 1 and 5 entries; and, regulators should have been adjusted with caution. As mentioned previously, air flowing out of the goaf into the No. 2 Entry could have been caused by excessive leakage through stoppings between the Nos. 2 and 1 entries outbye 9 XC. Such leakage would endanger face operations, reduce the airflows needed to remove heat as fast as it was being generated, and militate against diluting and sweeping away methane and spon-comb products.

Pressure differentials-- The Moura Ventilation Officer was one of many people who could have measured ventilation-pressure differentials, but did not. Measuring these differentials is as important to understanding airflows as is the measurement of your blood pressure to your doctor's diagnosis.

One simple yet informative task is monitoring the differential across regulators. As mining progresses, the differential should decrease almost linearly with distance. A greater decrease gives warning that airway resistances are excessive. No change or an increase gives warning of excessive leakage through stoppings.[23]

The differential should continue to decrease during retreat operations; again, an increase evidences leakage which, in turn, leads to inadequate ventilation through the goaf. Of course, should there be a major reduction in the quantity of air reaching the section, there might be a concomitant decrease in available pressure; these things must all be taken into account, brought to the attention of management, and understood, if not remedied, at the time of their finding.

SEALING

Stoppings constructed as the final seals for a goaf liable to spon comb must withstand a pressure of at least 345 kPa.[24] Based on considerable experience in the analysis and design of "explosion-proof" stoppings, I can state with reasonable engineering certainty seals like those constructed in 512 would likely be ruptured by an impulsive force of perhaps as much as one-tenth that pressure.

512 seals.-- The seals, ~2-1/2-m-high by ~8-3/4-m-wide,[25] were made of 100-mm-thick Tecrete[26] mesh blocks. Their 1-day compressive strengths might be as high as one-third their cured strengths,, assuming optimum water quality and proportions, curing temperatures, and moisture conditions.[27] Transverse strength data are not available; typically, these are 15 to 25 percent of the compressive strength.

Purportedly, 6 bolts were anchored in the roof, 6 in the floor, and 3 in each rib.[28] Although these bolts would increase the perimeter-friction factor and tend to fix the ends, they would provide little resistance to bending by explosion-induced impulsive forces.

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[23]Inadequate pressure in airflows into working faces historically has been the principal cause for ignitions of methane.
[24]3.5 (6) in the General Rules for Underground Coal Mines.
[25]Exclusive of hitches.
[26]Tecrete is a polypropylene-fiber reinforced lightweight concrete.
[27]Seals in the Nos. 4 and 5 entries might have been built prior to 6 August, and might have been stronger.
[28]It is not clear whether each seal had these bolts or only "prep" seals with door frames.

Explosion-proof seals.-- The minimum design parameters and potential adequacy of seals should be proven. This can be done, for example, in a noncoal, nongassy mine by igniting a stoichiometric methane-air body or detonating an explosive charge in a sealed chamber.[29] We have failed to find records of tests on the "explosion-proofness" of thin-wall seals as large as these.

"Explosion- proofness" is a function of a seal's transverse strength, and is proportional to the square of the ratio of its thickness to span. This ratio for the 512 seals approximated 1×10^{-4}. Seals with ratios almost 500 times greater could not withstand explosion-induced pressures of ~140 kPa.[30]

Explosion-proof plugs-- Based on studies in Germany, Great Britain, and the United States of America, to be considered "explosion-proof", seals used in large cross-sectional areas (19 - 22 m^2) should be a monolithic plug. Anhydrite, concrete, flyash cement, and gypsum are amongst the proven materials for this. Seal thickness should be at least one-third the width or height of entry, whichever is greater. In Moura No. 2 Mine that would be >2,900 mm, almost 30 times thicker than were the actual seals.

Temporary seals.-- Regardless, seals made of materials that require days-to-weeks to develop full strength (the strengths at which the above-referenced explosion tests were conducted), are inappropriate where time is not your friend. Time was no friend to Mouramen on 6 August 1994. For them, the minimum safeguard was to construct relief-vented, temporary seals made of materials such as dry-laid Omega block, and to withdraw all persons from the mine until behind-seal atmospheres stabilised.[31]

MONITORING BEHIND-SEAL ATMOSPHERES

Monitoring the atmosphere inbye seals is more critical to safety than any other thing related to sealing and future operations. The rule governing this or any monitoring program is: ***Bad data are worse than no data.***

Sampling system.-- Good data begin with the sampling tubes. There should be at least two. Two and even ten are far less expensive than is the borehole needed in the event of damage to a one-tube system. Sampling lines should extend at least two-crosscuts-deep into the sealed area. This militates against the effects of dilution from the exchange of gases between the open and "sealed" atmospheres.[32]

Each sampling point should have a pipe hung from the roof or wedged between the roof and bottom. Holes[33] along the length of the pipe increase the chance of getting a useful sample -- methane, hydrogen, and other low-density gases concentrate close to the roof while carbon

[29]Pressures developed using black powder simulate ignition of methane.
[30]U.S. Bureau of Mines, SMRE (Great Britain), and Versuchsgrube-Versuchstrecke (Germany) tests detailed in reports given to B. Lyne.
[31]See pages 99-109 and 118 in MINE FIRES (2nd. Ed.).
[32]Assume, for example, five seals through which the leakage rate averages 0.01 m^3/sec./seal. In one week, more than 30,000 m^3 of air will leak into the "sealed" area while an equal quantity of "sealed" atmosphere leaks out, enough to cause potential problems or explosions as in the Beatrice, Mary Lee, Oak Grove, Quinland, and Rossenheigh mines.
[33]The sum of the areas of the holes should equal or be less than the area of the tube through which the sample is drawn.

dioxide and other high-density gases may be close to the floor.[34]

Breach stoppings.-- Before sealing, all stoppings must be breached in the first two crosscuts or to the sampling points, whichever is farther. This minimises pressure differentials across the seals which in turn minimises exchanges of atmosphere between the sealed and open portions of the mine, the lower the pressure differential, the lower the rate of exchange. In conjunction with the proper siting of sampling tubes, this maximises the validity of samples.

512 Monitoring.-- There was only one sampling tube within 512. It ended ~20 meters inbye the seal in the No. 3 Entry, the belt entry on the intake-air circuit. Further, stoppings were not breached between that entry and Nos. 1 and 5 entries. The likely result would be the collection of samples containing the least quantities of CO, CH_4, and other "fire" gases.[35]

Samples were not obtained from or in the No. 1 Entry, the main return, the entry in which the highest concentrations of "fire" gases and methane were likely to be found. Because of that and the inadequacy of Sample Point 5, had there not been an explosion, the probabilities are samples would not represent conditions in 512 for quite a while. Decisions based on such samples would have kept Mouramen in harm's way.

Boreholes.-- Samples were drawn from boreholes, some previously drilled and some, like that into 512, drilled after the first explosion. The borehole into 512 was strongly positive (air blowing out) whereas all other holes were reported to be negative (air sucking in). Besides being a means for sampling, boreholes can "tell" us much about what is going on. For example:

a) When temperatures are colder on the surface than at the bottom of the borehole, flows tend to be positive; the greater the difference, the stronger the flows;

b) Boreholes close to and inbye a fire tend to become positive whereas those close to but outbye tend to become negative;

c) Negative flows that become and remain positive indicate the fire is growing or coming closer to the borehole;

d) Positive flows that have a major increase in pressure and quantity also indicate the fire is growing or coming closer to the borehole; however,

e) Positive flows that have a major increase in pressure but not quantity are more likely the result of changes in flow paths rather than in the fire.

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[34] Contrary to testimony given before the Enquiry, CO_2, when hot enough, may be found near the roof.

[35] Testimony given before the Enquiry was it would have been dangerous to place Sample Point 5 farther in. It was not dangerous. Knowing the Panel was to be sealed, the system could have been placed properly prior to slabbing pillars between 1 and 2 XC.

There is no record of these things having been studied. Gas samples, however, were obtained. Figure 4 is a graph of the CO/CO_2 ratios for the mine fan and for all holes from which samples contained gases from the first explosion. These show sharp rises in the ratios from 510 and 520 around Monday (8 August) midnight. As mentioned before, this ratio increases with temperature indicating the likelihood of growing fires in those places. GC and PGM data from 512 are too limited for analysis. Their relatively high ratios and the strong positive pressure from its borehole, however, give reason to suspect fire in 512 also.

Data from other boreholes indicate no important reactions in their areas. This is supported by the decreasing ratio as "seen" at the fan. The great disparities between the GC and PGM data emphasise the need for check-sample analyses and calibrations.

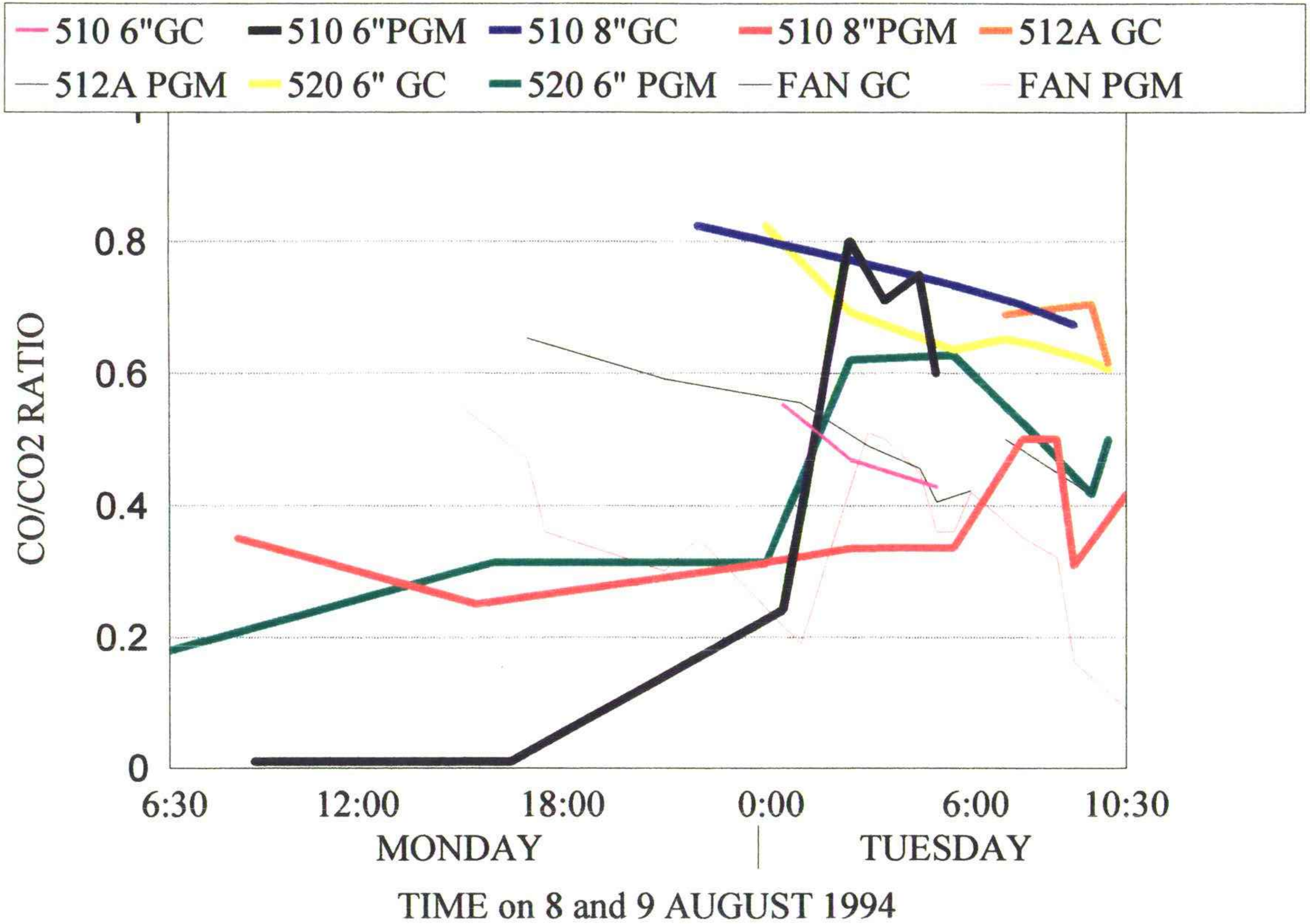

Figure 4. -- MOURA No. 2 MINE BOREHOLE GAS SAMPLES

dwm 28/12/94

SITE OF FIRST EXPLOSION

An explosion is initiated when an ignition source and a medium (i.e., fuel) capable of explosive combustion are brought together in a confined space. The result is the development of heat (i.e., energy) in the form of flame. In coal mines, in the absence of explosives and high-energy electrical arcs, the likelihood is that methane[36] would be the principal fuel. In the absence of important quantities of coal dust,[37] the total volume of flame seldom exceeds 4 to 5 times the original volume of the ~5 to ~15 percent methane-air mixture. Mixtures containing less than 7% methane will not likely cause development of damaging pressures.

Post-explosion borehole gas samples plus samples drawn from such places as the fan, Dips north return, pump room, and 1 Northwest return, places from which tube-bundle samples might have been representative, indicated 510, 512, and 5 South were the only places in which there were major concentrations of products of combustion. One of these, therefore, was the probable site of the first explosion.

<u>510</u>.-- Gas sample data[38] indicated pre-explosion methane concentrations monitored at Points 16 and 18 were below 1%. Neither large bodies nor outbursts of methane were likely to have been in 510. Had this, therefore, been the site of the first explosion it would not have contained enough fuel to cause the damaging pressures experienced in 1 Northwest and at the fan. In contrast, between the first and second explosion 510 contained explosive methane-air mixtures and a possible fire.[39]

<u>512</u>-- The evidence strongly supports belief that spon comb was active within 512. Spon comb is an igniting source when flames develop. That there was active flaming within 512 is not known; however, a rising temperature was indicated by the CO Make and CO/CO_2 Ratios shown in figures 2 and 3. Pre-explosion data from Point 5, ~20 meters inbye the "seal" in the No. 3 Entry,[40] showed methane rising above 7%, and thus the potential to cause damaging pressures if ignited. Post-explosion borehole samples indicated 512 contained explosive methane-air mixtures and a probable fire.[41]

<u>5 South and 520</u>.-- Gas sample data presented by SIMTARS[42] indicated pre-explosion methane concentrations were below 1% at Sampling points 6 and 7, at 5 South bottom, and in the top returns. Additionally, the continuous mining machine being used in the section had a methane monitor that purportedly would disengage electrical power into the working place should it sense concentrations in excess of 2%. Further, nothing was said or heard during the phone call just prior to and at the instant of the explosion to support the proposition the explosion was initiated by an outburst in 520 or 5 South.

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[36]Methane in this report is used generically; in actuality, methane found in coal mines includes other gases such as ethane, propane, butane, neon, and krypton.

[37]"Important quantities" typically are coal dusts having diameters less than 830 microns in concentrations exceeding 10,000 mg/m^3.

[38]<u>48 FINAL MAIHAK GAS CONCENTRATION</u>, File Ref: 10/012/0005, Source File: PT_DATA.WB1 presented by SIMTARS.

[39]CH_4 and CO/CO_2 borehole data from GC Point 3: 510 8", 08/08/94 -2200 hours to 09/08 0915 hours.

[40]See footnote 37.

[41]CH_4 and CO/CO_2 borehole data from GC Point 6: 512A, 09/08/94 - 0710 to 1009 hours.

[42]See footnote 37.

Had this been the site of the first explosion, therefore, it would not likely have contained enough fuel to cause the damaging pressures experienced in 1 Northwest and at the fan. Following the first explosion, borehole gas samples from 520 indicated the possibility of an active fire. Methane concentrations, however, were not high enough to cause the damages suffered during the second explosion, assuming, of course, samples from GC Point 4 520 6" were reasonably representative of the atmospheres within 5 South and 520.

RE-ENTRY

Stability is the key to safe re-entry. When atmospheres behind seals remain relatively constant for a long-enough period of time, there is good reason to expect them to remain as they were provided:

a) Seals were well constructed;
b) Strata around the seals are not too "leaky";
c) New massive falls within the sealed area are not likely;
d) Samples represent, as best they can, outflows from the fire; and,
e) Barometric pressures have been and remain reasonably steady.

There had been an explosion; therefore, plans for subsequent activities depended on knowing, without question where:

- Thermal reactions might be on-going as determined by trend-analyses of the oxides of carbon, oxygen deficiency, methane, hydrogen, and the higher hydrocarbons in each panel throughout the mine; and where,

- CO concentrations exceed 750 ppm, the maximum in which persons wearing SCBA should be permitted to travel.

A good start had been made to obtain these data. By 10 a.m. 9 August, a number of critical points were being sampled. Analyses indicated no important thermal reactions in and no dangerous outflows from panels in the north and from 1 to 3 South. The worsening atmospheres developing in the 510, 512, and 520 panels, however, obviated plans for re-entry.[43]

Stability-- As stated above, stability is the key to safety. For this reason, a cardinal rule in mine rescue and recovery is: ***Never change the ventilation without unquestionable, compelling reasons***. This rule was broken early Monday morning when ventilation in the mine was changed from that induced by one fan to the higher pressure and greater quantity induced by two fully-powered fans. The results of this change are neither known nor knowable. They might have been of no consequence; or, they might have admixed air into >15% bodies of methane; or, they might have moved flammable gas-air mixtures through hot spots. Such could happen in minutes, or, as it was in Scotia Mine, three days and 7 more dead miners later.

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[43] What happened to the samples taken in the hours just before the second explosion?

Stability also requires waiting long-enough between sealing and allowing persons underground. In high-volatile coal seams where there might be a fire, such as in Moura No. 2, good practice is to wait at least 72 hours or until the sealed atmosphere has gone outside the explosive region, whichever is later. The exception to this is where "explosion-proof" bulkheads have been constructed, though 72 hours isn't that many when lives are at risk.

If miners are believed to be alive, a long-enough period of time is never so clear. Where survivors might be and how long it would take teams to reach them is one factor. Are we in communication? How serious are their injuries? Do they have food, water, enough air? Are there enough teams to do the job? Can teams reach them without making potentially dangerous changes to the ventilation? Can they be reached by boreholes from the surface? This is no time for "guesstimates" or the taking of undue chances.

The future.-- Thought mightl be given to reopening Moura No. 2 Mine. The recovery of victims should not be a factor in decisions; the effects of two explosions plus fires plus time makes their recovery problematical.

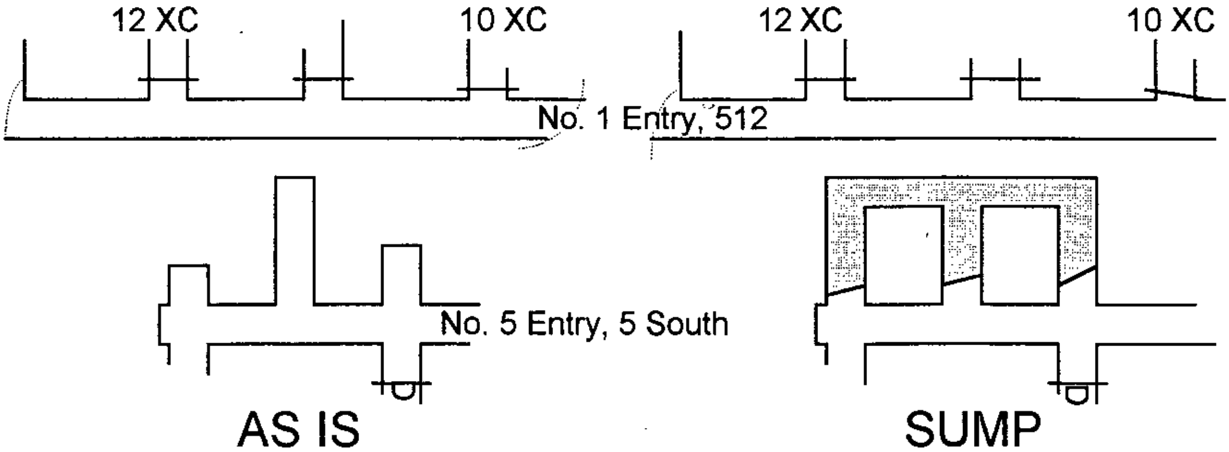
Except for economics, there is no reason why this mine or portions of it cannot be recovered. Plans, however, must be predicated on positive knowledge of what effects re-ventilation might have; on maintaining careful, correct mine sampling and analyses prior to and throughout the operation; and, having no fewer than ~~eight~~ six mine rescue teams.

OPINIONS

The most probably site of the first explosion was within the 512 Panel. The heating in 512 should have been "seen" in its early stages while remedial measures could yet have been taken. Subsequently, the heating should have been sealed effectively and mining operations resumed safely. Why, instead, was there an explosion? Why, instead, did 11 miners lose their lives while 10 others were put in harm's way? Is there something that can be done to militate against similar disasters in the future?

Good answers will be difficult to get. Evidence from the first explosion is scanty at best, and what is "found" in the future might represent either, neither, and combinations thereof. Answers to these and other pertinent questions cannot be found in statements and testimony given so far by the people involved. Inconsistencies in some of this testimony does not help. Did people actually travel in the goaf? If so, where? How? When? Was bottom actually taken in the No. 1 Entry? Where? Ambiguities abound.

One small example was the responses to the question about the extensions driven from 5 South towards 512. The testimony was that these were for a sump rather than for the connectors between panels common throughout this mine. The drawing on the left, below, shows the area in question; to the right is the same area as developed for a sump by most miners.



Another disturbing fact, from interview statements as well as testimony before the Enquiry, was the misknowledge of ventilation and spon comb. Management needs to develop and provide appropriate and repeated training and education in these as well as other facets of mining. Repeated training and education helps miners become alert to conditions and circumstances, and instills within them the responsibility for their own safety and the safety of those around them.

Most disturbing was learning that deputies and other managers often leave the mine for many tens of minutes while their assigned crews continue to work. One testified about going out before the end of his shift that fateful night. Repeatedly detailed during the course of the Enquiry was the Job Description emphasis on the duty and responsibility of deputies and other managers for the safety of persons assigned to them. How can a manager make proper and timely decisions regarding potentially unsafe conditions while he is outside? How can he withdraw his crew from the mine if he is outside? The well-established and accepted practice of "smoko" is inconsistent with safe, productive mining.

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