A TECHNICAL EVALUATION OF INFORMATION PROVIDED BY THE DEPARTMENT OF MINERALS AND ENERGY BRISBANE, QUEENSLAND, AUSTRALIA

concerning the

UNDERGROUND COAL MINE EXPLOSIONS MOURA #2 MINE MOURA, QUEENSLAND, AUSTRALIA AUGUST 7 and 9, 1994

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A TECHNICAL EVALUATION: MOURA #2 MINE EXPLOSIONS

INTRODUCTION

On August 7, 1994, an underground coal mine explosion occurred at the Moura #2 Mine, located near Moura, Queensland, Australia. Prior to the safe recovery of the mine, a second explosion caused the sealing of the mine at the portals. Mr. J. Davitt McAteer, Assistant Secretary of the Mine Safety and Health Administration (MSHA), United States Department of Labor (USDOL), offered technical assistance to the Department of Minerals and Energy in Australia. Following the initial exchange of technical information, a video conference was held on September 21, 1994 to clarify and discuss the material provided.

The Department of Minerals and Energy provided MSHA with information that they had assembled since the occurrence of the first explosion. However, the technical information was limited to that which was gathered from surface locations. Additional information from a complete underground investigation would be necessary before the causes and origins of the explosions could be determined with certainty.

This report is intended to provide insight concerning the fuel involved in the first explosion, the point of origin, the determination of the extent of the explosion, the magnitude and direction of the explosion forces, and an evaluation of the gas concentrations that were observed after the first explosion.

PRELIMINARY EVALUATION OF THE MOURA NO. 2 EXPLOSION

Many factors must be evaluated to determine the cause of an underground mine explosion. These include the total quantity, concentration, and possible locations of any methane accumulations prior to the explosion, the point of origin, and the likelihood that coal dust contributed to the development and propagation of the explosion. The extent of flame and the magnitude and direction of primary explosion forces are necessary elements in an explosion investigation. Evidence for this purpose is gathered during the underground investigation, from interviews, autopsy reports provided by the Medical Examiner, and the results of all laboratory work performed on evidence directly related to the explosion. Without a complete underground evaluation of all the evidence, including the effects of the explosion on the underground workings, conclusions can only be considered preliminary.

FUEL INVOLVED IN THE EXPLOSION

Examining the products of combustion from an explosion can be useful in determining the hydrogen to carbon ratio of the fuel expended in the combustion process. The hydrogen to carbon ratio of the fuel is given by the H/C Index. The form of the H/C Index used in this analysis is shown in Equation (1).

$$\frac{H}{C} = \frac{1.073\%N_2 - 4\%O_2 - 4\%CO_2 - 2\%CO + 2\%H_2 + 4\%C_2H_4}{\%CO_2 + \%CO + 2\%C_2H_4} \qquad (1)$$

The H/C ratio for various fuels is shown in Table 1.

TABLE 1. - Examples of H/C Ratios for Various Fuels		
FUEL	FORMULA	H/C RATIO
Bituminous coal	-	.7
Acetylene	C_2H_2	1.0
Gasoline	-	2.0
Propane	C_3H_8	2.7
Ethane	C_2H_6	3.0
Methane	CH_4	4.0

When using the H/C Index to determine the fuel of combustion, certain requirements are necessary to obtain reliable results. They can be summarized as follows:

1. The product gases should be collected as close to the explosion site as possible.
2. The product gases should be collected as soon as possible after the explosion (minimum elapsed time).
3. The gas sample collected should not be diluted with air outside reasonable bounds (i.e. maximum 19-19.5% oxygen).

In addition to the above conditions, it is necessary that the analysis of the gas sample be internally consistent. That is, all factors that affect the accuracy and precision in analyzing each individual gas (O_2, N_2, CO_2, etc.) should be similar. A measure of this internal consistency is given by the calculation of a standard deviation associated with the H/C Index. The calculation of the standard deviation was done using Equation (2).

$$SD = A\left[1.151(\%N_2)^2 + 16(\%O_2)^2 + \left(4 + \frac{H}{C}\right)^2(\%CO_2)^2 + \left(2 + \frac{H}{C}\right)^2(\%CO)^2 + 4(\%H_2)^2 + 4\left(2 - \frac{H}{C}\right)^2(\%C_2H_4)^2\right]^{\frac{1}{2}}$$

$$\text{Where:} \quad A = \frac{.003}{\%CO_2 + \%CO + 2\%C_2H_4} \qquad (2)$$

For the standard deviation calculation, it was assumed the accuracy of the gas standards used was ±1%.

An attempt was made to identify the fuel involved in the explosion by using the H/C Index from selected gas chromatograph results of samples collected immediately following the explosion. Data from locations G5STH (9), G13CT (8), G17CT (10), G25CT (7), and G4SL (5) were rejected for this calculation since all samples were collected after the second explosion. Samples from G510-6 (2) and G Fan were too diluted with air to give meaningful results. None of the portable gas monitor readings were used due to suspected internal inconsistencies of the data. Thus, only samples collected at locations G510-8 (3), G512A (6), and G520-6 (4) prior to the second explosion could be utilized to interpret the fuel of the first explosion.

The 16 gas suites from the 3 locations used for the calculation of the H/C Index are shown in Table 2.

TABLE 2. - Gas Suites Used in Calculation of H/C Index

SITE G510-8 (3)

Elapsed Days	H/C	SD	CH_4	CO	H_2	CO_2	O_2	N_2+Ar	N_2	C_2H_6	C_2H_4
0.93	3.52	0.18	13.81	0.779	0.486	0.946	15.5	68.4	67.59	0.0085	0.0304
0.93	3.54	0.18	13.8134	0.7785	0.4858	0.946	15.4992	68.4378	67.63	0.0085	0.0304
1.12	3.41	0.21	12.0968	0.6379	0.397	0.8265	16.2718	69.7365	68.91	0.0073	0.0257
1.24	3.43	0.25	11.3174	0.5477	0.3391	0.747	16.6692	70.3497	69.52	0.0065	0.023
1.32	3.50	0.30	9.6879	0.4492	0.278	0.6382	17.2971	71.6249	70.78	0.0055	0.0189
1.40	3.57	0.32	9.3601	0.4157	0.2557	0.6177	17.4257	71.9006	71.05	0.0058	0.0182

SITE G512A (6)

Elapsed Days	H/C	SD	CH_4	CO	H_2	CO_2	O_2	N_2+Ar	N_2	C_2H_6	C_2H_4
1.31	3.81	0.29	8.7575	0.4617	0.2857	0.6699	17.3481	72.4418	71.59	0.0059	0.0203
1.40	3.87	0.41	6.5097	0.3468	0.2177	0.4914	18.2714	74.14	73.26	0.0043	0.0149
1.44	3.46	0.51	5.3213	0.2588	0.16	0.4206	18.8166	75.0067	74.12	0.0037	0.012

SITE G520-6 (4)

Elapsed Days	H/C	SD	CH_4	CO	H_2	CO_2	O_2	N_2+Ar	N_2	C_2H_6	C_2H_4
1.01	3.62	0.26	6.06	0.595	0.35	0.7224	17.7	74.5	73.62	0.0061	0.0145
1.11	2.52	0.29	6.8602	0.4704	0.2965	0.6802	18.0233	73.6426	72.77	0.0056	0.0208
1.25	2.72	0.34	6.2271	0.388	0.2415	0.6108	18.3007	74.2086	73.33	0.0051	0.0179
1.31	1.91	0.57	3.7234	0.2488	0.1471	0.3816	19.4256	76.0494	75.15	0.0029	0.0104
1.36	2.45	0.44	4.7201	0.3119	0.1835	0.486	18.932	75.3491	74.46	0.0037	0.0132
1.41	2.33	0.43	4.91	0.309	0.19	0.5	18.9	75.2	74.31	0.0039	0.0141
1.43	2.13	0.56	3.96	0.2403	0.1412	0.3965	19.3363	75.9117	75.01	0.0029	0.0106

Figure 2 is a plot of the H/C Index and associated standard deviation as a function of time for the location G510-8 (3). Here again, the H/C Index indicates a methane explosion.

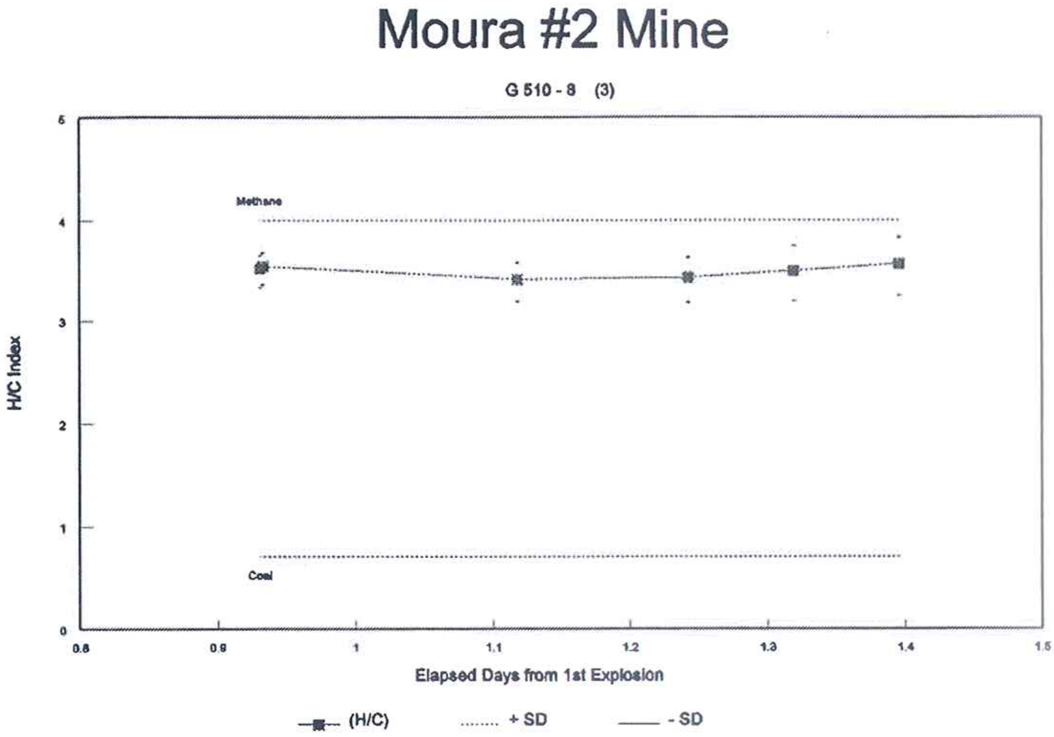


FIGURE 2. - H/C Index Versus Time for Site G510-8 (3)

Figure 3 is a plot of the H/C Index and associated standard deviation as a function of time for the location G520-6 (4). For this location, the H/C Index ranges in value from 3.62 to 1.91, generally decreasing in time. This suggests possible coal dust involvement in the original explosion and/or localized fire burning during the 36-hour period after the first explosion.

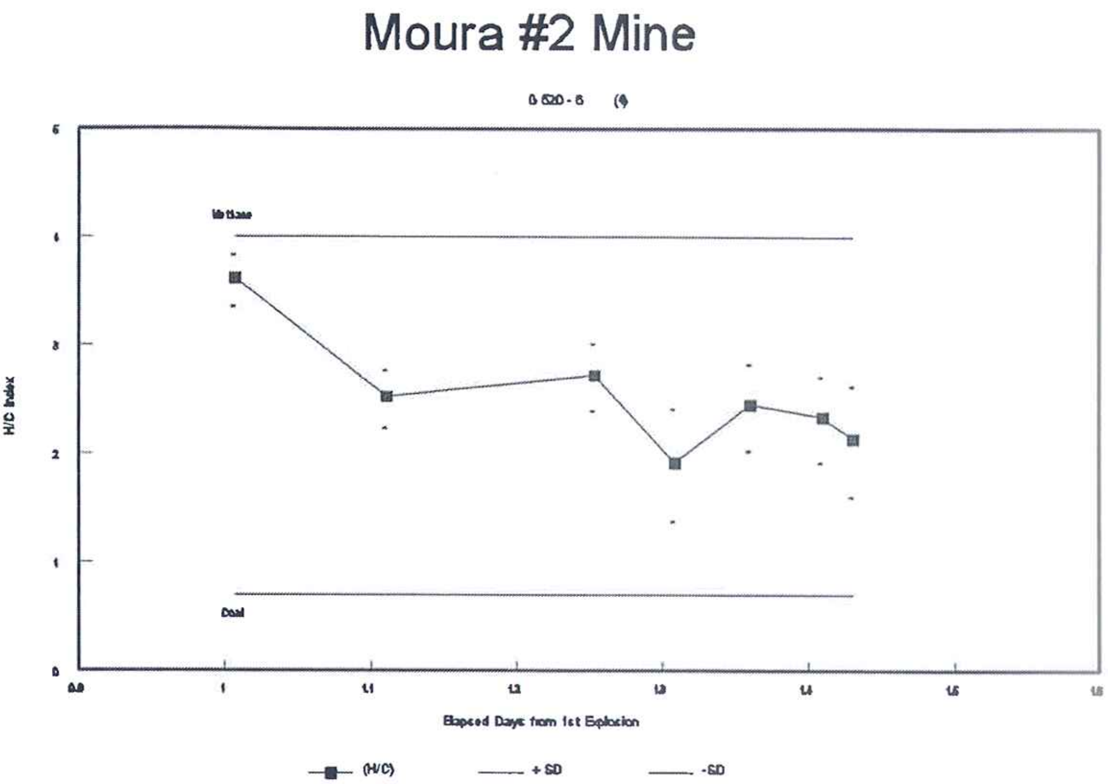


FIGURE 3. - H/C Index Versus Time for Site G520-6 (4)

The gas analysis data from locations G512A (6) and G510-8 (3) indicates a possible methane explosion. Gas analysis data from location G520-6 (4) is consistent with coal dust involvement and/or a localized fire burning during the 36-hour period after the first explosion.

Although methane has been tentatively identified as the primary fuel for the first explosion, it is impossible with the available information to quantify the amount of methane consumed. Based on experience, it is reasonable to assume that only a small quantity of methane within the explosive range was available for the first explosion - probably less than 2,000 cubic feet. It is expected that quantities of methane in excess of 2,000 cubic feet would result in pressures that would have caused greater effects on the surviving miners.

IGNITION SOURCES

Based on the currently available information, at least two possible ignition sources must be considered. First, there was evidence of spontaneous combustion occurring in the 512 Panel. It remains a possible ignition source in a potentially explosive atmosphere. Second, history has repeatedly shown that the direct actions of miners have resulted in over 90% of all ignitions or explosions in the United States since 1872. Miners were assigned to work in the 510 Panel near the 512 Seals before the explosion. The results from the continuous monitors in the area did not indicate any accumulations of methane. However, the airflow patterns in the 510 panel could not be conclusively determined. The results of the continuous monitor at location 18 appears inconclusive. Therefore, without an underground investigation, it is impossible to determine the adequacy of the ventilation in the 510 panel and the possibility of methane accumulations can not be eliminated.

A review of the available information, such as gas concentrations and reported forces, minimizes the possibility of the explosion being initiated from 5 South. However, this could only be completely eliminated by a thorough underground investigation.

FLAME

All physical evidence within the explosion zone should be evaluated for signs that would indicate the presence or lack of flame at each particular location. During the underground investigation, mine dust samples would be taken throughout the mine. These samples should be analyzed for incombustible content and for the presence of coking. The incombustible content of the mine dust should be sufficient to eliminate coal dust as a fuel for an explosion. With incombustible contents below 65%, coal dust and float coal dust can contribute flames and forces to a methane explosion. Low incombustible contents can also allow for the occurrence of an explosion fueled by coal dust or float coal dust, in the absence of methane or other fuels.

All of the mine dust samples should also be analyzed for coking by means of the Alcohol Coke Test. This chemical analysis for coke is more sensitive than visual observations and coking can be found beyond the areas where coke was visually observed. Research on coke formation and deposition in experimental explosions has proven that coke indicates the passage of flame. Coke is produced by a relatively slow-moving flame and is not formed where the mine dust initially contained more than 50% incombustible.

For the first explosion, it has been theorized that an explosive concentration of methane accumulated in the vicinity of the 512 seals. Methane concentrations further into the goaf would steadily increase until the upper explosive limit was exceeded. Sufficient flame and force was associated with the initial methane explosion to suspend and ignite coal dust. The propagation of the methane and coal dust explosion may have continued into portions of 5 South.

The data supplied by the Department of Minerals and Energy has been used to make an estimate of the area involved in the initial explosion and the type of explosion that occurred. The data examined included the SIMTARS time plots of CO, CH_4, O_2, and CO_2 concentrations for tube bundle sampling locations, gas chromatograph results for samples collected at ten locations, and portable gas monitor readings from six sampling sites.

The SIMTARS time plots are the only data available that provide baseline concentrations prior to the explosion at 11:40 p.m. on August 7, 1994. On the basis of this data, it appears that the point of origin for the explosion could have been near the tube bundle sampling Point 5 in the 512 Panel. Over the 24-hour period prior to the explosion, this is the only location which indicated slowly increasing concentrations of CO (from 0 to about 150 ppm) and CH_4 (from 0 to about 5 percent). However, even though monitoring stations were being used in the 510 panel, a ventilation deficiency could have allowed methane to accumulate in this area and be undetected by the monitoring stations. It, therefore, cannot be dismissed without a thorough underground investigation.

FORCES

The actual point of ignition of an explosive mixture always occurs at a very specific point. This point of ignition must be located within a body of fuel that occurs at a concentration within its explosive limits. The explosive limits of methane are approximately 5% to 15%. Immediately after the ignition of the fuel occurs, a fireball develops and rapidly engulfs the entire cross-sectional area of the mine. This initial development of the flame can take up to eight (8) seconds prior to propagation. After initial flame development is complete, propagation of the flame through the fuel mixture occurs in all directions.

Pressure development in an underground coal mine explosion is caused by heating of the atmosphere during the combustion process. The heating of the atmosphere causes the involved gases to expand. This expansion causes the air ahead of the flame front to compress and exert a force on objects and mine surfaces. The primary forces generated during an explosion always travel away from the point of ignition in all directions, thus establishing a transition zone. However, even after the flame is extinguished, the primary explosion forces continue to travel away from the source of ignition. A mine map detailing the direction of the primary explosion forces could only be determined by an underground investigation.

Tests by researchers on the physiological effects of blast pressure have shown that a peak overpressure of about 1 psi will knock a person down, 5 psi is the minimum pressure that will cause damage to the eardrums, 15 psi results in lung damage, 35 psi is the threshold for fatalities, and 65 psi results in fatalities to 99% of the people exposed to such pressures.

Also, research has shown that a properly constructed block stopping with mortared joints can fail with a pressure as low as 4 psi and drywall stoppings with both sides coated with a suitable sealant fail at about 2 psi. These values are affected under certain conditions such as if the stopping is bearing any load, if a drywall stopping is only coated on one side, or if the stopping is not otherwise properly constructed.

Coke accumulations occur on the side of material and equipment nearest to the source of ignition in low pressure conditions. As the pressures rise, coke accumulations are deposited on both sides of material and equipment. Research has shown that coke accumulations occur on the side opposite to the direction of force when pressures are high. Actually, in this latter case, coke deposits occur around the entire object, but the force of the explosion removes the coke accumulation from the side facing the oncoming pressure wave.

Based on the data received, it appears that the original methane accumulation was probably ignited in the 512 panel or in the 510 entries near the 512 seals. A low order explosion generating approximately 5 psi began to propagate. The limited quantity of available methane prohibited the explosion flame from propagating to 5 South. However, insufficient quantities of incombustibles did not arrest the participation of coal dust in the explosion. As the explosion entered 5 South, the forces generally increased to approximately 8 psi as additional coal dust fueled the explosion. A pressure wave of about 4 psi may have traveled to the face of the 5 South section.

Based on reports of the survivors and the layout of the mine, it was concluded that:

1. The incombustible content of the mine dust may have been insufficient to prevent the involvement of coal dust in a methane explosion,

2. The methane accumulation was probably diluted to less than 9%,

3. This accumulation may have been ignited near the 512 seals,

4. Upon ignition of the methane, a fireball expanded and involved approximately 5 times the volume of the initial explosive methane accumulation, which would have probably been limited to the area near the 512 seals,

5. The flame speed during the initial methane explosion has been estimated to be about 600 feet per second,

6. The pressure wave which the crew in 5 South experienced was probably on the order of 4 psi,

7. The original methane accumulation was ignited and a low order explosion generating approximately 8 psi began to propagate. (As the explosion propagates, it loses about 50% of its intensity as it turns 90 degree corners.)

Nearly all of the explosions that have occurred in underground coal mining resulted from the direct actions of persons in or near to the transition zone. The transition zone identifies the location of the probable point of origin. In attempting to determine this location, investigators must evaluate the following factors:

1. The location of the victims after the explosion,

2. The magnitude and direction of primary forces and the extent of flame,

3. The location of potential ignition sources located throughout the area of the 512 seals, in the 510 panel and within the 5 South section,

4. The location of roof falls, water accumulations, and other obstructions,

5. A determination of the incombustible content throughout the workings,

6. The condition of approved equipment used on the section,

7. The possible presence of smoking materials, and

8. The potential ventilation deficiencies located throughout the mine which may have allowed methane accumulations to occur. These deficiencies include but are not limited to;

   A. The lack of ventilation controls throughout areas of the mine affected by the explosion,

B. Short circuits within the ventilation system,

C. Contour of coal seam and change in barometric pressure, and

D. Possibilities of roof fall in the goaf pushing methane outby the 512 seals.

After evaluating all of the available information, the evidence suggests that the explosion may have originated in the area identified as the 512 panel or in the 510 panel near the 512 seals. Although several potential ignition sources existed in this location, evidence indicates that either spontaneous combustion or the actions of men working in the vicinity of the 512 seals most likely were responsible for the August 7, 1994 explosion.

BAROMETRIC PRESSURE

Barometric pressure readings were recorded at the Thangool Airport, which is reportedly the closest airport to the mine. Figure 4 is a graph of the barometric pressure from August 4 through August 9, 1994. Figure 4 indicates that a slight decrease in barometric pressure occurred in the hours prior to the first explosion. Any decreases in barometric pressure prior to an explosion would create the potential for methane to migrate from the sealed areas into the active workings. Therefore, this does not eliminate the possibility that methane could have migrated from the sealed 512 panel and into the active workings of the mine.

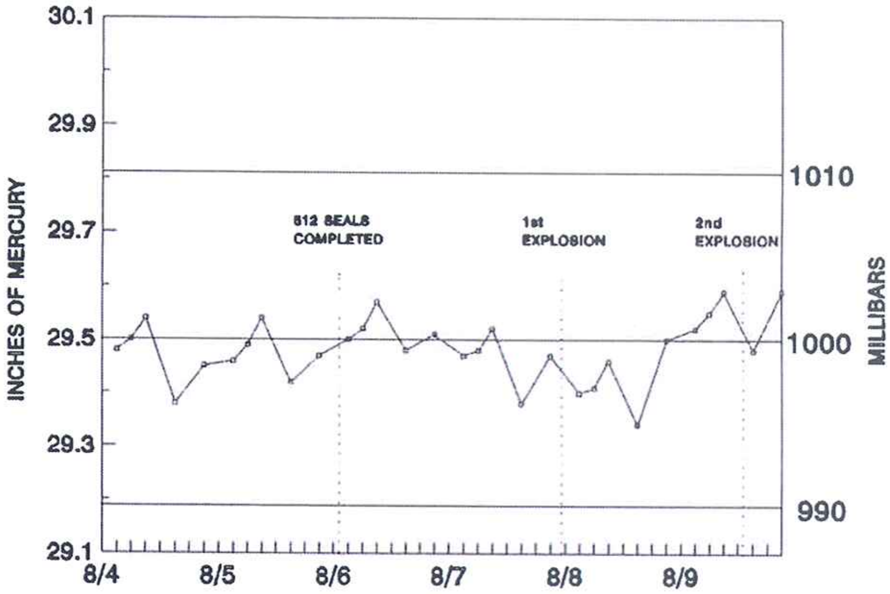


Figure 4 - Barometric pressure

GAS CONCENTRATION ANALYSIS

An analysis of the results from the tube bundle system after the first explosion indicated the atmosphere at locations 5, 6, 7, and 16 were similar. This could be due to the sampling lines being damaged to cause sampling of the same location, or the ventilating air for the locations being the same due to damage to ventilation controls in these areas. A review of these results also indicated that concentrations of carbon monoxide in excess of 1000 ppm existed for an extended period. A steady decline in these readings also indicated that the ventilation controls in 5 South may have been damaged but were generally intact. If the samples lines into the 510 and 512 panels were intact after the first explosion, it indicates that the 512 seals were damaged, if not destroyed, and at least some of the ventilation controls in the 510 panel were intact. Limited airflow was occurring in the 510 and 512 panels. Two graphs showing the concentrations at Points 5,6,7, and 16 are attached.

An analysis of the gas chromatograph results was also completed. These results indicated the potential for CO levels in excess of 1 percent at the G520-6 (4) and the G510-8 (3) borehole locations. Oxygen levels at these locations were potentially less than 14 percent. The rate of reduction in concentration of CO and the rate of increase in concentration of oxygen were used to estimate the concentrations of these gases at the time immediately after the explosion. For each of the estimates, the greatest dilution rate was assumed which would indicate worst case situations.

The CO concentration at the G520-6 (4) borehole would be most representative of the concentrations on the active working section. The worst case concentration at the sampling point could have been in excess of 1 percent CO. The concentration of oxygen at this location could have been as low as 14 percent.

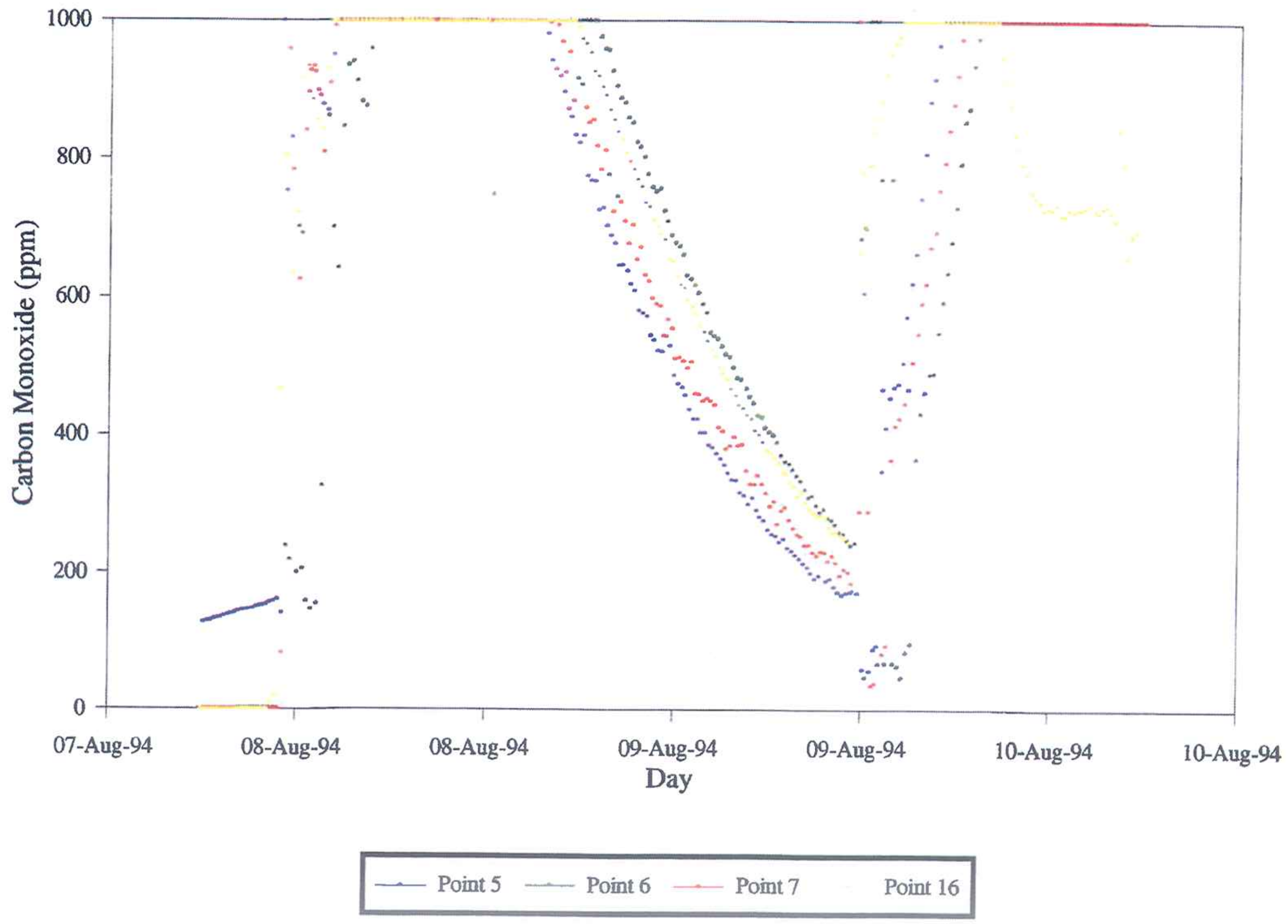
The concentrations of CO at G510-8 (3) could have been in excess of 1 percent, with depressed oxygen concentrations as low as 12 percent. No estimates could be made for sampling location 6 due to the limited data. The results from location 2 indicated significant airflow was available at this intersection following the first explosion.

The rate of dilution in the gas concentrations obtained at locations 3 and 4 also indicate that some ventilation may have been present in the 510 panel and 5 South sections following the first explosion, with a greater quantity of flow in the 5 south panel. This indicated that some of the ventilation controls may have remained in place following the first explosion, which is consistent with the analysis of forces caused by the first explosion.

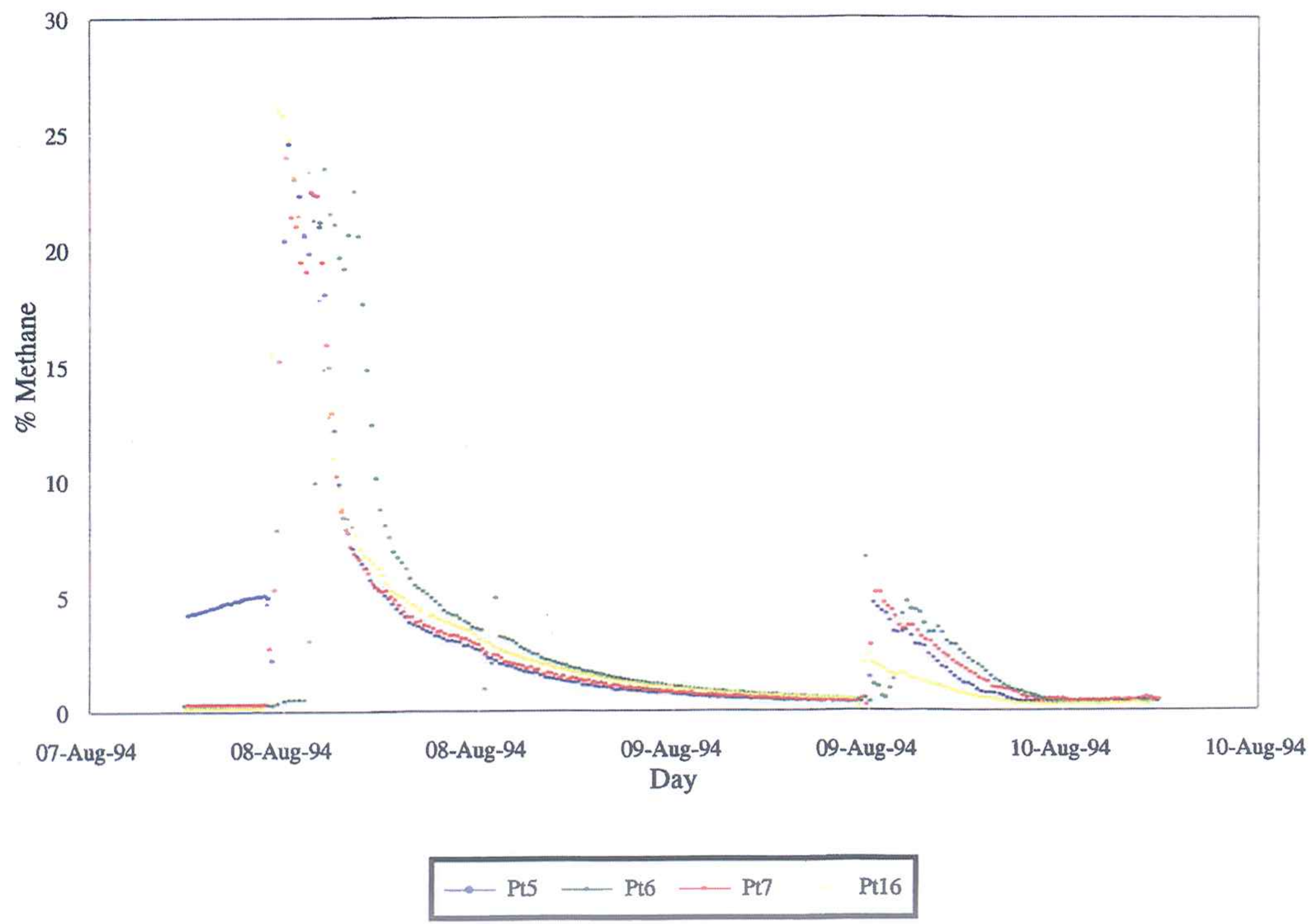
As it appears that the ventilation controls in 5 South were not significantly damaged, contaminants from the first explosion could have been swept into 5 South and spread throughout the active faces.

Results of gas chromatograph analyses indicate the second explosion destroyed a significant portion of the ventilation controls, possibly damaged methane transmission lines underground, and possibly damaged seals used to isolate other areas of the mine due to the rapid and extreme rise in methane levels at location Point 2.

CARBON MONOXIDE



Methane



30
25
20
15
10
5
0
% Methane
07-Aug-94
08-Aug-94
08-Aug-94
09-Aug-94
09-Aug-94
10-Aug-94
10-Aug-94
Day
Pt5
Pt6
Pt7
Pt16