The Scientific Analysis and Interpretation of the Moura No.2 Gas Monitoring Data

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SUMMARY

Whilst it was not possible to enter the Moura No.2 underground mine after the two explosions that occurred on 7 and 9 August 1994, there was a comprehensive set of gas monitoring data available from a combination of sources. This enabled detailed analysis to be undertaken. Data from the tube bundle was augmented by borehole data. These data enabled identification of the types of explosion and the probable cause of the first explosion. This was identified as a heating in the recently sealed 512 panel. It is the believed that the first explosion was methane gas explosion originating in this panel. Additional data were then obtained from deputy shift reports and ventilation surveys to investigate whether the heating had been active prior to sealing. The data discussed in this paper includes all data available to the mine staff prior to the first explosion and all other data subsequently discovered during the investigation/inquiry process. The report by the Mining Warden outlines the full investigation into the accident including probable causes (Windridge, 1995). This paper is limited to a scientific evaluation of the gas monitoring data available.

BACKGROUND

Moura No. 2 underground coal mine was a bord and pillar mine practising partial pillar extraction on second workings. The coal contained a significant methane seam gas. There had been at least one episode of a heating in a panel prior to the sealing of 512 panel. The panel working was completed on Friday 5 August 1994 and sealing commenced immediately. Sealing was completed at approximately 1:00 am on Sunday morning. A tube bundle gas monitoring point was retained through the seal in no. 3 roadway part way into the goaf. Other monitoring locations are shown in figure 1. Figure 1 also shows the location of the supplementary boreholes where additional gas analyses were obtained. At approximately 11:30 pm on Sunday 7 August 1994 there was an explosion underground, 11 men perished and 10 men survived. At approximately 12:20 pm on Tuesday 9 August 1994 there was a second and much more powerful explosion. The decision was then taken to seal the pit.

The SIMTARS investigation team ascertained the status of the Maihak tube bundle monitoring system and by analysis the probable locations of the sample points after the first explosion. The monitoring system at Moura No. 2 consisted of Maihak Unor infrared analysers for carbon monoxide, carbon dioxide and methane, and a paramagnetic Oxygor analyser for oxygen. The data set was adjusted for minor analyser errors particularly in the oxygen analyser. Detailed analysis was then undertaken on this data set and that obtained from the boreholes. Borehole analysis was undertaken both by continuous analysers (Maihak Sifors and a Teledyne paramagnetic Oxygen analyser) and by gas chromatograph. The CAMGAS system enabled a complete gas analysis on each bag sample not only for the gases detected by the continuous analysers but also for hydrogen, nitrogen, ethylene and ethane.

THE DETERMINATION OF THE TYPES OF EXPLOSION

In order to determine the type of explosion that has occurred it is usual to analyse the post explosion gases in two ways; Jones - Trickett (JT) ratio and the Hydrogen to Carbon ratio (H/C).

Based on the work of Jones and Trickett (1955) the JT ratio calculates the number of molecules of fuel consumed per molecule of oxygen. For a pure methane explosion the JT ratio should be 0.5 and for a pure coal dust explosion 0.7 - 0.9, depending on the type of coal. In between these values it would be a hybrid explosion. The equation used is:

$$JTR = \frac{CO_2 + 0.75CO - 0.25H_2}{0.265N_2 - O_2}$$

where the atmosphere prior to the explosion is assumed to contain fresh air mixed with a fuel gas or coal dust. Tube bundles do not directly determine the nitrogen content and do not determine the hydrogen content. Therefore the JT ratio derived from tube bundle data is only an approximation, tending to cause an underestimation of the JT ratio. Gas chromatography permits an accurate determination.

The H / C ratio is simply the ratio of hydrogen present (in any form) in the post explosion gases to the carbon present (in any form) in the post explosion gases. The amount of water produced by the explosion is estimated from the difference between the loss of oxygen and the production of other oxygenated species such as carbon monoxide and carbon dioxide (Hofer and Giardino, 1990). Strictly, this ratio can only used when a determination all the major species present has been undertaken. However tube bundle data can be used as a first approximation as the only major constituent missing would be hydrogen itself and an uncertainty in the nitrogen concentration as it is calculated by difference. The ratio of hydrogen to carbon in coal is approximately 0.7 where as for methane it is 4.

Analysis of the tube bundle data obtained from gas samples immediately after the first explosion analysed on the tube bundle system (the CAMGAS system was not used until 5 hours after the explosion) indicated a JT ratio of between 0.45 and 0.6. The H/ C ratio was determined to be between 3.1 and 5.5. Despite the approximations involved an essentially methane explosion is clearly indicated. Gas chromatographic analysis of borehole data confirmed a H/C ratio of between 3.4 and 3.7 and a JT ratio of between 0.5 and 0.6.

Analysis of the post second explosion gases revealed that this explosion was probably a hybrid methane and coal dust explosion. This explosion was of much greater force than the first, causing damage to the main fan and ejecting debris out of the shaft. Analysis of the tube bundle and borehole gas monitoring data indicated that there were probably a number of fires underground causing a reversal of the normal ventilation flow.

THE SOURCE OF THE EXPLOSION

At the time of the explosion the only known area containing an explosive gas mixture was the recently sealed 512 panel. Indeed the tube bundle monitoring data indicated that it had only just exceeded the lower explosive limit when the explosion occurred. A detailed analysis of the tube bundle monitoring data from the sealed area was then undertaken using a wide range of techniques (Cliff 1995). A comparative analysis with data obtained from the sealing of the 401-402 panel was also undertaken in an effort to identify any abnormal gas concentration behaviour. Figures 2 to 5 show the comparison. The analysis showed the following:

- A rate of CO production 4 times that of 401-402
- A rate of oxygen depletion 3 times that of 401 -402
- A Graham's ratio (CO to O2 deficiency ratio) exceeding 1 prior to explosion (401-402 did not exceed 0.4)
- A carbon monoxide to carbon dioxide ratio exceeding 0.1 prior the explosion (401-402 did not exceed 0.03)

It is interesting to note the spikes appearing in the 512 data refer to the tube integrity check carried out during day shift on 7 August 1994.

The normal range for Graham's ratio (Graham, 1921) is between 0 and 0.4. For the CO to CO2 ratio (Rhead and Wheeler, 1910) at room temperature values less than 0.05 are expected. These normal ranges were confirmed by laboratory tests carried out by SIMTARS staff on samples of Moura No.2 coal taken from the stockpile.

Indeed the last data obtained from 512 panel prior to the explosion had Graham's ratio at 6.2 and the CO/CO2 ratio at 0.38. This is indicative of a rapidly worsening heating behind the seals.

In the absence of any other probable source of ignition, it was therefore concluded that the probable source of ignition was a spontaneous combustion within 512 panel.

EVIDENCE PRIOR TO SEALING

SMELL

At the inquiry , three reports of an unusual smell, June 17 , June 24 and August 5, were identified. Smell is a complex indicator of the presence of spontaneous combustion. This is due to the difficulty of describing objectively the nature of the smell,and the fact that the smell will disappear if the ventilation system is altered or dilution of the odoriferous air stream occurs. One can only detect a smell if one is standing in the odoriferous air stream. SIMTARS has carried out many tests where the off gas from a coal undergoing a heating has been passed around groups of miners. Particularly where the temperature of the coal heating is less than 150 ° C, there is a wide variety of description of the odour, with a significant proportion unable to identify any odour at all.

CO MAKE

Ventilation survey measurements were undertaken regularly in the top and bottom returns of 512 panel by mine staff. These measurements were undertaken at varying frequency. SIMTARS combined all CO make measurements available prior to the explosion with those made available during the inquiry. Figure 6 depicts the CO make curves for a number of panels during second workings. CO make is the amount of carbon monoxide generated per unit time within a section as measured in litres per minute. The CO make from 512 panel quickly became higher than all previous panels except 5 North panel where there had been an acknowledged heating. However the extraction system used in 512 was different to that used previously, generating significantly more coal per unit time. It was decided by the mine staff , that this enhanced extraction rate was the cause of the high CO make. The majority of the data associated with the second increase in CO make was not available prior to the first explosion, and as such the rapid rise in CO make could not have been fully appreciated.

It raises the question at what level of CO make should there be concern. There is no fixed answer. Undoubtably there are many factor influencing the rate of generation of CO from coal including its inherent reactivity, pore structure, rate of mining, temperature of the coal etc. The best answer is the first significant deviation from the normal range of values for the pit/seam/panel that is being worked.

The CO make for 512 was higher than previous panels and the second rapid rise is even more unusual. Certainly in hindsight, using the full CO make data set, the data are consistent with a spontaneous combustion occurring in the goaf of the 512 panel.

OTHER INDICATORS

Analysis of the tube bundle gas monitoring data prior to sealing did not reveal any abnormal behaviour in either gas concentrations or derived ratios. This is due to the significant volumes of air ventilating the panel (approximately 40 m3/sec). It is not possible to calculate Graham's ratio accurately as the oxygen deficiency is small and inaccurate near the fresh air limit.

This does not indicate that there was no spontaneous combustion occurring merely that the spontaneous combustion was confined to a relatively small mass of coal and not spreading rapidly or increasing in intensity.

CONCLUSIONS

The gas monitoring data indicate that the probable source of the first explosion at Moura No. 2 was a spontaneous combustion within the recently sealed 512 panel. Some indication of the heating prior to sealing may have been given by the presence of a smell and a higher than normal CO make.

The second explosion that occurred on 9 August was probably a hybrid methane - coal dust explosion.

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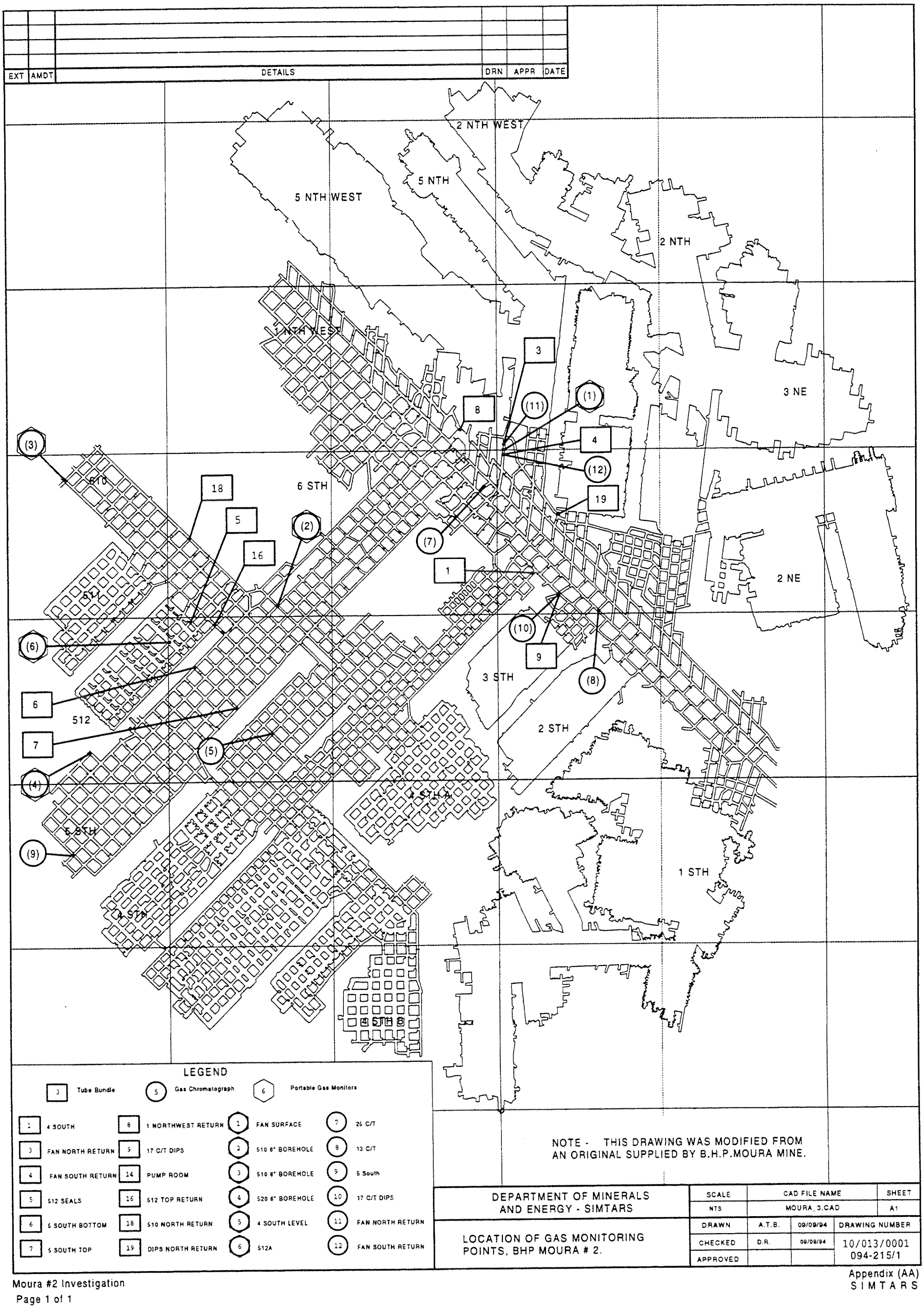

Figure 1. The mine plan

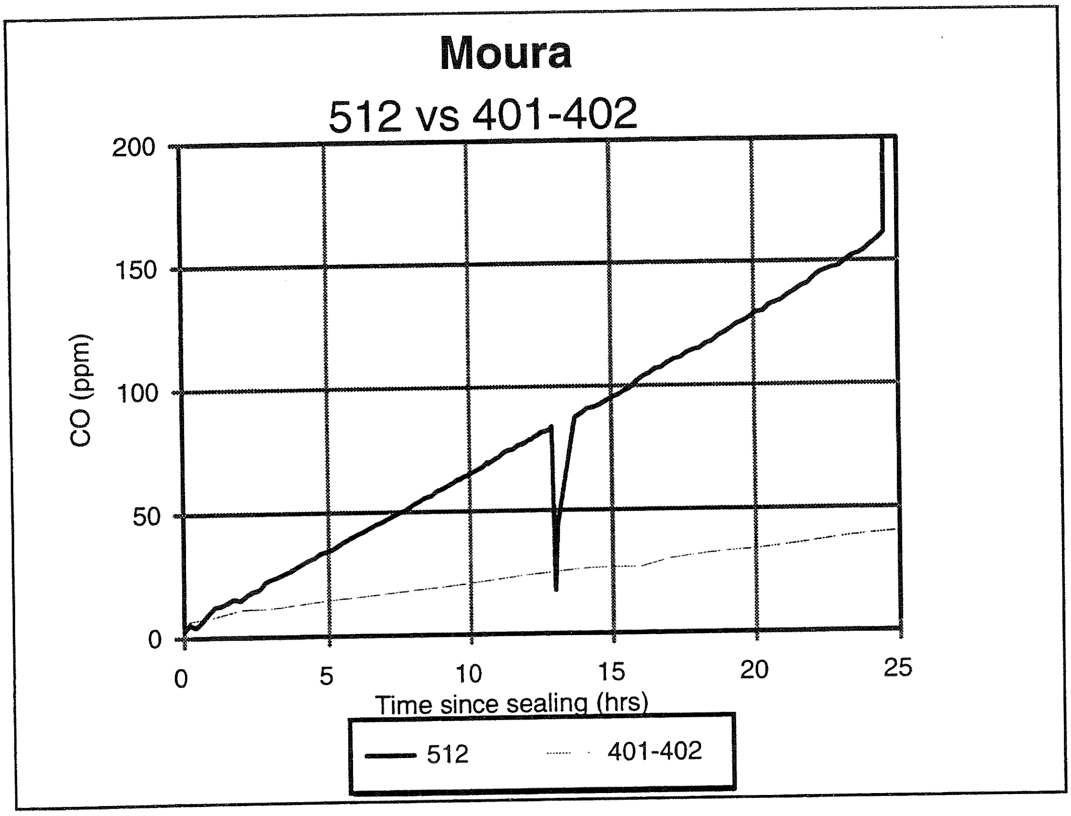

Figure 2. Carbon monoxide concentration as a function of time since sealing completed.

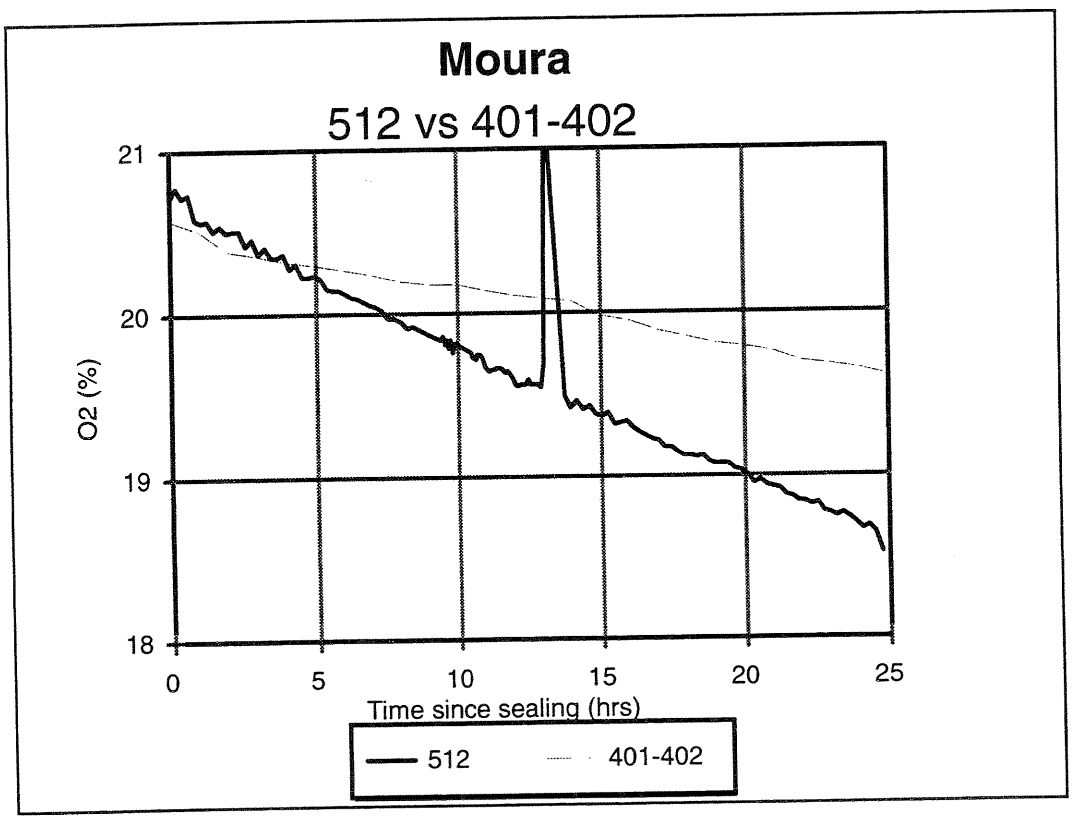

Figure 3.Oxygen concentration as a function of time since sealing completed.

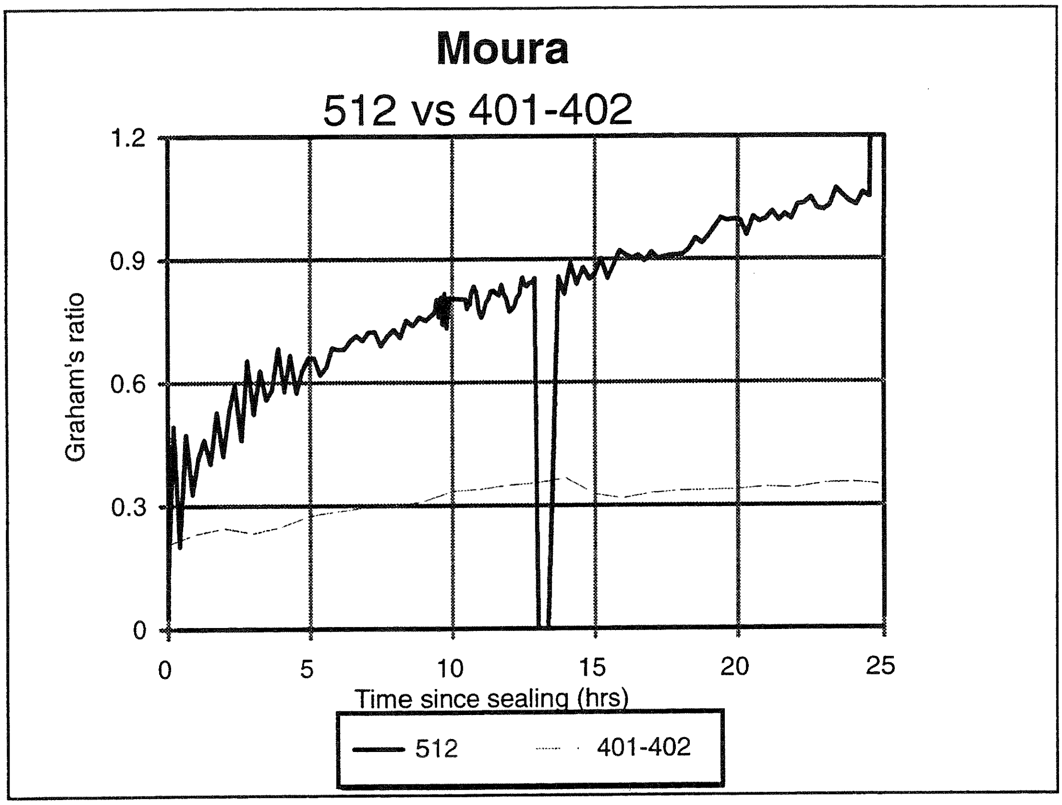

Figure 4. Graham's ratio as a function of time since sealing

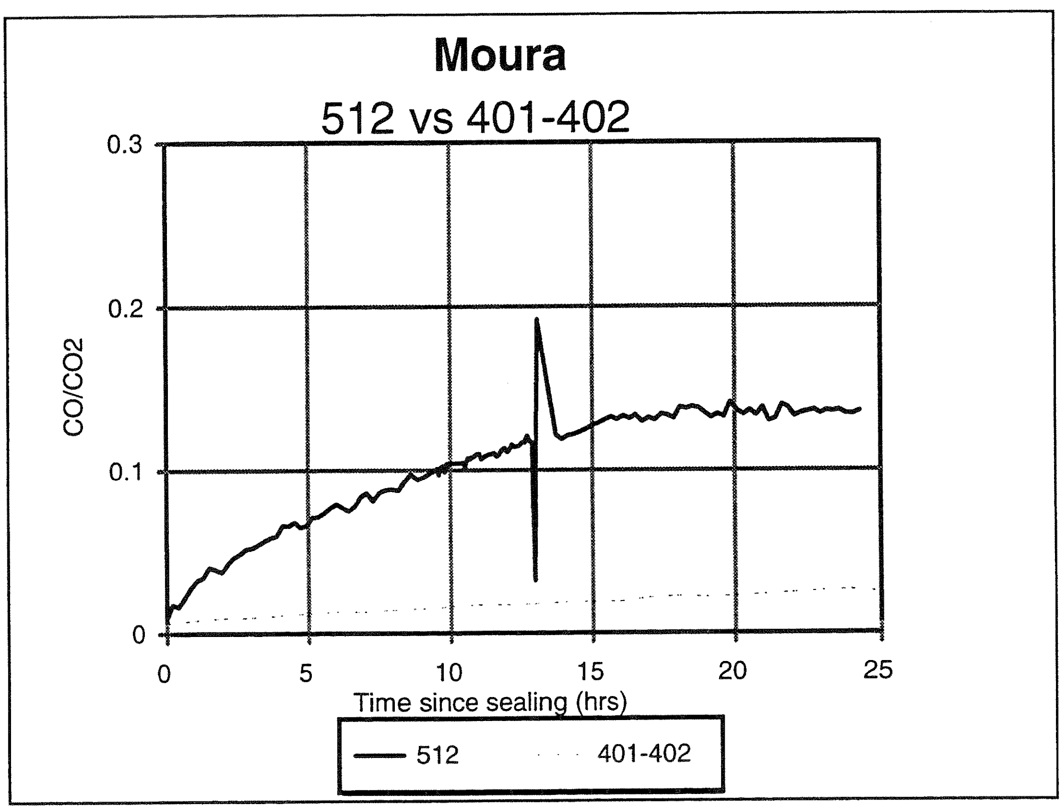

Figure 5. The CO to CO_2 ratio since time of sealing.

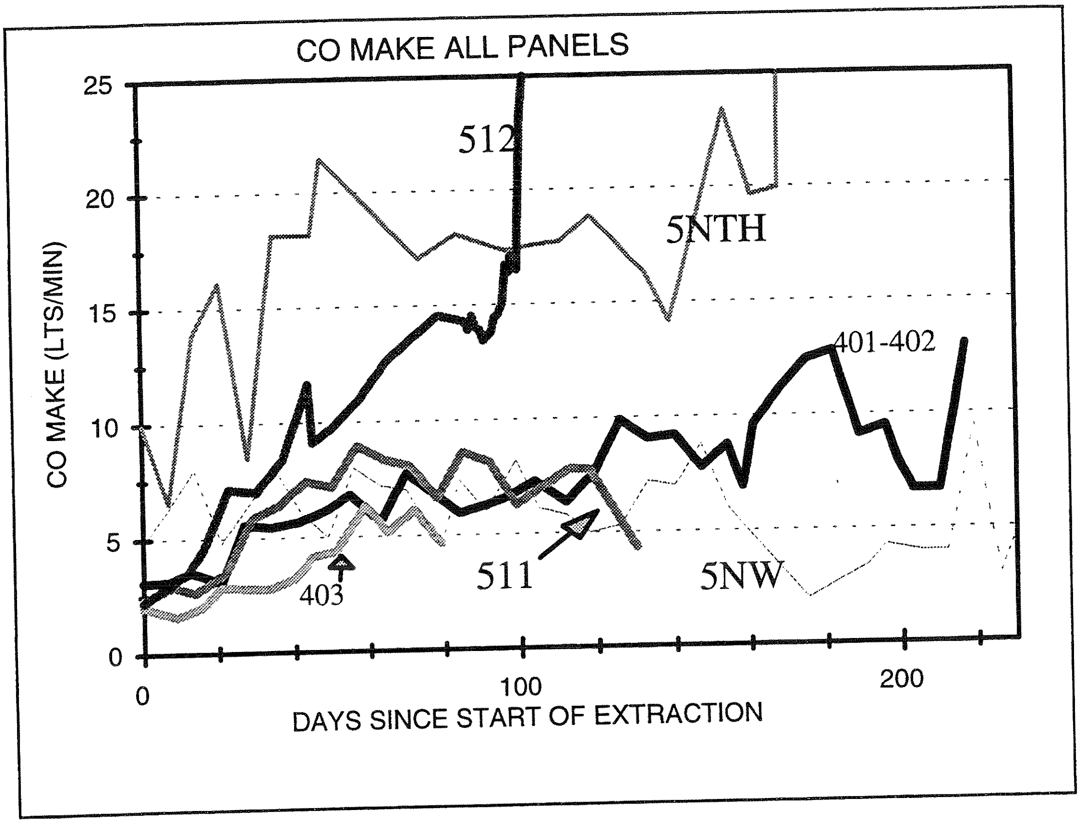

Figure 6. Comparison of CO makes for the most recent panel sealings.