GAS ANALYSIS AND INTERPRETATION IN ACCORDANCE WITH THE MINES RESCUE SERVICE NEW SOUTH WALES (NSW) EMERGENCY PREPAREDNESS AND MINES RESCUE GUIDELINES

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ABSTRACT

While the occurrence of heatings and fires can result in serious consequences in an underground coal mine, no other event has the potential to cause catastrophic loss of life than that of an explosion.

When any of the above incidents occur it is essential that an effective decision making process is undertaken to properly manage the situation. Part of this process involves the analysis and subsequent interpretation of the mine atmosphere. This paper looks at the function of the Mines Rescue Service NSW in this area with regard to the Emergency Preparedness and Mines Rescue Guidelines.

INTRODUCTION

In the event of a heating fire or explosion, and men are missing or trapped underground, rescuers may be asked to respond and assist in their location and rescue. In these situations it essential that the decision-makers have access to the analytical and interpretative expertise to make these evaluations.

In an emergency situation the Incident Management Team provides the mechanism for these decisions to be made. The team will often include technical experts in this field, or at least have access to them.

In NSW the Mine Manager or senior mine official has the statutory responsibility for the management of an emergency operation. However, the Mines Rescue Manager has the full responsibility for the operation and deployment of the Mines Rescue Brigade. He must ensure that prior to deployment of brigadesmen underground, the relevant atmospheric information is available.

The requirements of the Mines Rescue Guidelines in relation to these issues will be discussed.

MINES RESCUE GUIDELINES

In Australia the Mines Rescue Service NSW, in conjunction with the Mines Rescue Board NSW, has developed Emergency Preparedness and Mines Rescue Guidelines to provide assistance to Incident Management Teams and Mines Rescue Service officers in regards to their responsibilities and conduct in an underground emergency.

These guidelines also detail explosibility risk categories with entry exclusion limits for rescue brigadesmen (see Table 1). Methane only is the entry restrictive gas that is considered when calculating these exclusion limits.

In addition to the risk categories, information is also provided on the flammability and nature of gases, gas sampling and gas analysis and interpolating the lower and upper explosive limits (LEL and UEL) of relevant flammable gases.

RISK CATEGORY	Lower Risk Category Limit % LEL CH_4	Upper Risk Category Limit % UEL CH_4
3 - Training purposes	40	-
2 - No life at risk	60	160
1 - Lives at risk	80	140

Table 1 - Risk categories for entry and rescue of personnel

The risk categories detailed in Table 1 apply when entry into a mine is proposed for the rescue of personnel. However, entry should not be considered, under normal circumstances, when the LEL and UEL calculations indicate a risk category of 1 or 2.

A Modified Ellicott's diagram is used to graphically display the risk categories and entry exclusion limits (see Fig 1). This type of diagram is preferred as it is also the current method used by the NSW Mines Rescue Service for explosibility trending. Ellicott's diagram is an extrapolated Hughes and Raybold diagram that trends explosibility data on a single 4-quadrant diagram that defines 'Explosive', 'Non-Explosive' and two 'Potentially Explosive' zones.

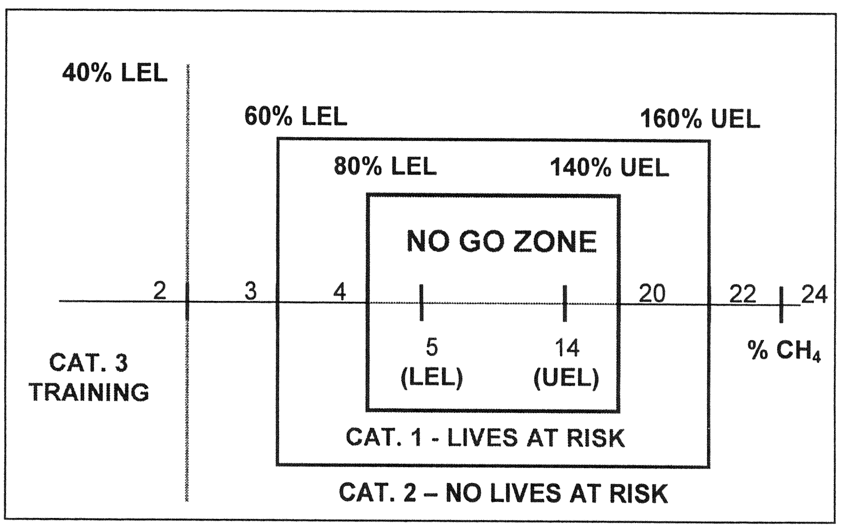

Fig. 1 – Modified Ellicott's diagram showing the "Risk Categories"

The Mines Rescue guidelines also emphasise that gas analysis must be accurate, reliable and trended. While the LEL and UEL can be determined or estimated using a number of analytical tools, such as multigas detectors and fixed monitoring systems, a mine wide monitoring system is preferred and also the incorporation of a gas chromatograph.

SAMPLING AND ANALYSIS OF MINE ATMOSPHERES

Many mines have access to a variety of analytical tools that can provide ongoing atmospheric analysis that enable trending of data. These commonly include portable multigas gas detectors, fixed sensor telemetry and tube bundle gas monitoring systems. Some mines in NSW also incorporate gas chromatographic systems. In a mine emergency, current and historical data from these systems can be of great value to Incident Management Teams in making their assessment of the situation. Colliery "normal" background gas concentrations and gas analysis data from previous incidents will also be of value.

During an emergency situation the normal gas sampling methods using gas sample bag collection, telemetry systems and tube bundle sampling may not be possible due to the inaccessibility of the required location. Quite often gas sampling must be undertaken from existing boreholes that may be limited in number and not located in the areas of concern. In these cases it may not be possible in the short term to make decisions in relation to deployment of personnel underground.

In NSW the Mines Rescue Service operates a technical division that runs independently from the regional rescue stations. It has state of the art gas chromatographic and gas analysis equipment, sampling equipment and two mobile laboratories (see Fig 2). It also maintains remotely installed gas chromatographic systems (SMARTGAS systems) on site at collieries that can be used routinely and during mine emergencies. The division has trained and qualified technical officers who can operate the equipment and provide enhancement and interpretation of results.

While other multigas analytical systems have been developed, the value of a gas chromatograph in providing reliable, complete and accurate gas analysis during mine emergencies cannot be overstated. It is arguably one of the most useful analytical tools available, requiring minimal operator setup and training. A single system can readily provide gas analysis data that would normally require a number of alternative methods to be used, and provide the determination of components that may not be possible using conventional analysers (ie analysis of hydrogen, nitrogen, hydrocarbons, etc). The introduction and subsequent development of ultra fast gas chromatographs has resulted in significant reductions in analysis times for an analysis. Using this type of system, gas samples can be analysed in one to two minutes.

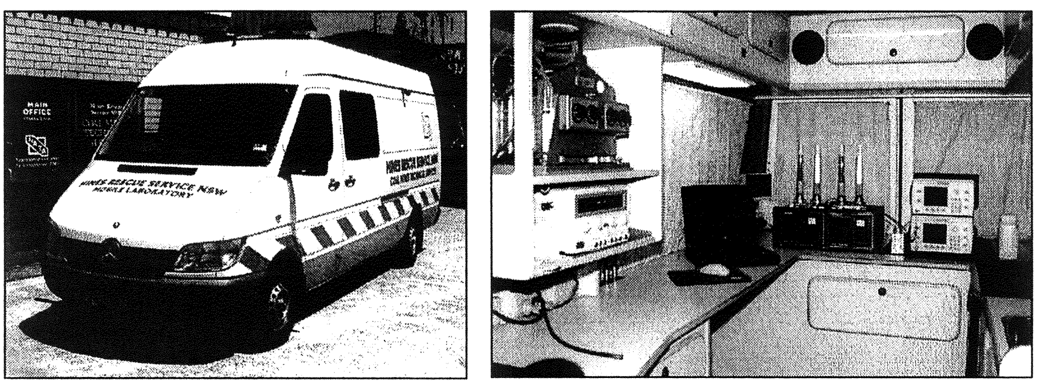

Fig. 2 - Mobile laboratory and typical internal layout

GENERAL INTERPRETATION OF GASES

The NSW Mines Rescue guidelines state that "*The explosibility of the mine atmosphere must be continuously monitored to ascertain that atmospheric conditions and trends are known*".

There is a variety of published data available detailing useful ratios and data manipulation calculations that can be used for post incident interpretation. These can be used to determine the extent of a heating or fire, temperature approximations and rate of progress.

The interpretation of complex gas mixtures should only be carried out by people who are experienced and trained in the field. There are however some simple rules that should be observed when interpreting gas analysis results:

- It is better to make no interpretation than report an incorrect one.
- Analysis from a few strategic points with a higher frequency is preferable to sampling from many points with less frequency.
- If a result deviates from an established trend, it should be re-checked or re-sampled.
- Understand the gas make of the colliery under non-mining conditions
- Confirm the validity of all externally received results.
- Individual results do not indicate the progress of an incident. Trending of results should be used.

Generally, relatively few indicators are commonly used for trending of results. These include carbon monoxide trending, carbon monoxide make, carbon monoxide/ carbon dioxide ratio, Graham's ratio and Trickett's ratio. The word "trending" is commonly used in the interpretation of gases. It generally refers to ongoing data collection and recording from individual sampling sites over a period of time. The data may be raw analytical data or calculated indicators such as those listed above.

A brief description of the commonly used indicators, and other ratios and indices that are used by the NSW Mines Rescue Service to assist in the interpretation of atmospheric analysis, include:

Carbon Monoxide Trending

For the trending of carbon monoxide to be effective, its normal background level must be established. Most collieries in NSW routinely monitor and trend carbon monoxide at various locations in their ventilation circuit and some sealed areas. Compensation must be made for ventilation changes, dilution effects, contamination by other sources, etc. It does not indicate intensity, making it difficult to distinguish between an extensive low temperature oxidation and a small intense heating.

Carbon Monoxide Make

Carbon monoxide make equates to the production of pure carbon monoxide in litres/ minute. It can be calculated by taking a simultaneous measurement of the carbon monoxide concentration and ventilation flow.

It is useful for the initial detection and monitoring the progress of the heating. However, as is the case with carbon monoxide trending, it does not distinguish between an extensive oxidation and a small intense heating.

The following points should be noted:

- The carbon monoxide make is not corrupted by nitrogen injection.
- It is not disguised by high air flows.
- It does not necessarily relate to the temperature of the coal. If the carbon monoxide make is high but hydrogen or higher hydrocarbons are absent then an extensive oxidation may exist but not an intense heating.

- Collieries should set appropriate trigger levels based on their own conditions.

The following levels detected in a normal extraction panel may not be indicative of Australian mines but have been used overseas:

< 10 litres/ min.	- NORMAL
10 - 20 litres/ min.	- INVESTIGATE IMMEDIATELY AND REPORT TO MANAGEMENT
20 - 30 litres/ min.	- EXTREME DANGER

Air Free Analysis

Air free analysis is used to calculate out the atmospheric air from the results of a gas sample. This is useful when trending results to eliminate the dilution effects from air leakage/ contamination of gas samples. This contamination can be due to leakages in sample lines, bag samples, or as a result of seals breathing in.

An example of it's usefulness can be found in the trending of carbon monoxide, where air dilution from an increase in ventilation could be misinterpreted as a decrease in carbon monoxide from the source.

Similarly, methane and carbon dioxide free analysis can also be used to reduce the masking affect that these components may exhibit when they are present in high concentrations.

Graham's Ratio

Graham's ratio is the ratio of the carbon monoxide produced in relation to the oxygen consumed. It is directly proportional to the temperature of the coal. It is generally used as a spontaneous combustion indicator. It is one of the most commonly used spontaneous combustion indicators currently used.

When using this ratio the following should be considered:

- Each mine should establish their own levels.
- Accurate determination of the nitrogen concentration is required.
- Graham's ratio is not affected by dilution with fresh air, carbon monoxide or methane.
- It is corrupted by the introduction of nitrogen or oxygen deficient atmospheres in the intake air.
- The ratio gives no indication of the extent of the heating.
- An increase in the ratio indicates an increase in coal temperature.
- Different results are obtained for old and new coals with older coals resulting in higher Graham's ratios.
- Care must be used when using the ratio in sealed areas as the lack of ventilation may not reflect the actual state of the heating. In some instances it has provided meaningful information for a few days after sealing

Different coal types will result in different values for the ratio. Some typical values reported from European coals are:

0.4 - Normal
0.5 - Check
1.0 - Heating
2.0 - Serious heating
3.0 - Active fire

Young's Ratio

Young's ratio is similar in calculation to Graham's ratio, with the exception that the carbon monoxide is replaced by the carbon dioxide as the oxidation indicator.

The calculation can be adjusted for the carbon dioxide interferences from air and other sources (ie seam gas).

When using this ratio the following should be considered:

- Increasing values indicates an increase in the oxidation intensity.
- Other sources of carbon dioxide may limit its use.
- Other limitations of Graham's ratio are also applicable. Ie corruption with the introduction of nitrogen or oxygen deficient atmospheres in the intake air.

Tracer Gases

Tracer gases relate to the appearance of hydrogen, ethylene and propylene in the evolution of gases. Ethylene and propylene are only produced by the thermal degradation of coal. A gas chromatograph is required to accurately identify their presence in the ventilation circuit.

Carbon Monoxide/ Carbon Dioxide Ratio

This ratio is commonly used in the United States of America and rises to a constant level of approximately 0.4 at about 200°C. It drops to approximately 0.1 when there is a blazing fire.

The calculation can be adjusted for the carbon dioxide interferences from air and other sources (ie seam gas).

When using this ratio the following should be considered:

- After sealing, indicators can be difficult to use because of the absence of a defined airflow.
- Problems can occur with carbon dioxide coming from other sources, such as seam gas, diesel engines, etc.
- The ratio is independent of oxygen deficiency. This overcomes some of the issues associated with ratios that are dependent on oxygen deficiency.
- It is unaffected by methane or air dilution.
- It is based on the change in ratio of carbon monoxide produced to carbon dioxide as a function of the coal temperature.

Typical values documented by SIMTARS, Australia, for Bowen Basin coals are:

$<$0.02 - Normal
0.05 - Coal Temperature ~ 60°Celsius
0.10 - Coal Temperature ~ 80°Celsius
0.15 - Coal Temperature ~ 100°Celsius
0.35 - Coal Temperature ~ 150°Celsius

The above values are indicative only and may not be applicable for other coal types.

Trickett's Ratio

Trickett's ratio is the oxygen required for combustion over the oxygen consumed by the combustion. It can be used as an indicator to determine the fuel component and also the intensity of oxidation.

When using this ratio the following should be considered:

- The ratio is corrupted if nitrogen is introduced.
- Similar problems occur with high methane make.

- Fresh air dilution of the fire products has no effect in Trickett's ratio.
- A ratio result of >1.6 is not possible. In this case there is an error in either sampling or analysis.

Typical theoretically calculated values for the ratio are:

0.5	- Methane fuel
0.7 to 0.9	- Coal fuel
1.0 to 1.6	- Timber Fuel

Willett's Ratio

Willett (1952) proposed this ratio for use in instances where the carbon monoxide produced by normal oxidation, heating or fire, does not disappear over time due to secondary reactions or adsorption onto the coal. In this case Graham's ratio cannot be used.

When using this ratio the following should be considered:

- The ratio increases with increasing combustion activity.
- May be a more effective ratio than Graham's ratio when monitoring behind seals.
- When the ratio remains constant this may indicate no activity.

Litton Ratio

Litton and Kim devised this ratio (1989) to specifically determine the state or level of activity of a coal fire behind a seal.

When using this ratio the following should be considered:

- A ratio of less than 1 tends to indicate a stable atmosphere behind the seal. However, the period of stabilisation at this level must be monitored for at least 30 days (Timko and Derrick, 1995).
- Even at a level of less than 1, any change in value may indicate equilibrium has not been reached.
- Active fires may result in calculated ratios in excess of 1000.

Apart from the ratios and indices detailed above, the Mines Rescue Service also uses the Ellicott's diagram to trend explosibility and, as described previously, graphically display the risk categories for entry into a mine.

TRENDING OF ATMOSPHERIC ANALYSIS

A number of software programs are available where data from atmospheric analysis can be entered with automatic calculation and trending carried out. In the case of the NSW Mines Rescue Service a spreadsheet program is used called SMARTMATE. This spreadsheet format simplifies the use for an operator and also allows additional ratios and subsequent trending and plotting to be easily added if required.

Generally, at least two indicators should be used for trending. The indicators selected will depend on the nature of the occurrence. While some ratios and indices may be suitable for use in monitoring a spontaneous combustion situation, they may not be suitable for use when monitoring fires or explosions or from behind a sealed area. SMARTMATE, and similar programs, provide help information that the user can access to assist in selecting the most appropriate options.

An example of the data entry page of SMARTMATE can be seen in Fig. 3.

SELECT TO RE-CALCULATE GRAPHS AFTER DATA ENTRY

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SMARTMATE

Version 3.1
April 2003

Sample Name/ Type: Ulan - No. 2 Upcast Shaft, 11/08/1991

RESULTS (% V/V) — * Indicates zero combustibles in calcula

No.	DATE / TIME (hh:mm AM/PM)	H_2	O_2	N_2	CH_4	CO_2	CO	C_2H_4	C_2H_6	HHC	Ambient Temp° C	Borehole Temp. °C	Relative Humidity	Bar. Press.	Air Flow m^3/sec	Explosive State	Spec
1	11/08/91 07:00 AM	3.2400	13.50	75.90	1.27	3.25	2.8400									EXPLOSIVE	
2	11/08/91 08:00 AM	3.1600	13.60	76.01	1.22	3.27	2.7400									EXPLOSIVE	
3	11/08/91 09:00 AM	3.1600	13.80	75.98	1.21	3.13	2.7200									EXPLOSIVE	
4	11/08/91 10:00 AM	3.1600	13.60	75.93	1.25	3.30	2.7600									EXPLOSIVE	
5	11/08/91 11:00 AM	3.2500	13.40	75.92	1.30	3.36	2.7700									EXPLOSIVE	
6	11/08/91 12:00 PM	3.2400	13.40	75.94	1.30	3.36	2.7600									EXPLOSIVE	
7	11/08/91 01:00 PM	3.2200	13.40	76.08	1.30	3.27	2.7300									EXPLOSIVE	
8	11/08/91 02:00 PM	3.1400	13.50	76.07	1.30	3.27	2.7200									EXPLOSIVE	
9	11/08/91 03:00 PM	3.0000	13.90	76.23	1.24	3.11	2.5200									EXPLOSIVE	
10	11/08/91 04:00 PM	3.0000	14.00	76.19	1.23	3.08	2.5000									EXPLOSIVE	
11	11/08/91 05:00 PM	2.1900	13.70	78.08	1.07	2.83	2.1300									POT.EXP	Impact of N
12	11/08/91 06:00 PM	1.7300	11.20	82.42	0.76	2.42	1.4700									POT.EXP	
13	11/08/91 07:00 PM	1.4400	9.64	84.90	0.64	2.19	1.1900									POT.EXP	
14	11/08/91 08:00 PM	1.3200	8.91	86.00	0.59	2.09	1.0900									POT.EXP	
15	11/08/91 09:00 PM	1.2800	8.50	86.53	0.58	2.06	1.0500									POT.EXP	
16	11/08/91 10:00 PM	1.3200	8.40	86.48	0.60	2.09	1.1100									POT.EXP	
17	11/08/91 11:00 PM	1.3300	8.30	86.58	0.60	2.09	1.1000									POT.EXP	

RESULTS / HELP INFORMATION / AIR FREE / CH4 FREE / FLAMMABILITY DATA / RATIOS / EXPLOSIBILITY ASSESSMENT / GRAHAM'S YOUNG'S RATIOS

Fig. 3 – Data entry page of the SMARTMATE data trending spreadsheet

Once the analytical data is entered into SMARTMATE, a number of options are available for the user, including input of additional relevant information, help information, air free data, flammability data, ratio trending, explosibility assessment and a range of graphical presentations relating to the entered data.

To illustrate all the available functions and data presentations of SMARTMATE would require more detail than is intended for this paper. However, Fig. 4 has been provided to illustrate typical ratios that are calculated and trended using the spreadsheet.

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SMARTMATE

Sample Name/ Type: Ulan - No. 2 Upcast Shaft, 11/08/1991

RATIOS

No.	Date / Time	Grahams Ratio	Young's Ratio	H2/ O2 Def. Ratio	Tricks. Ratio	H2/CO Ratio	CO/CO2 Ratio	CH4 Make L / sec	CO Make L / min	Willett's Ratio	Litton Ratio
1	11/08/91 07:00 AM	42.94	48.80	48.99	0.69	1.14	88.00			3.76	12.84
2	11/08/91 08:00 AM	41.88	49.63	48.30	0.69	1.15	84.38			3.78	12.57
3	11/08/91 09:00 AM	42.94	49.05	49.88	0.69	1.16	87.55			3.63	12.93
4	11/08/91 10:00 AM	42.32	50.25	48.46	0.70	1.14	84.22			3.82	12.68
5	11/08/91 11:00 AM	41.23	49.68	48.37	0.69	1.17	82.99			3.88	12.32
6	11/08/91 12:00 PM	41.05	49.64	48.18	0.69	1.17	82.69			3.88	12.28
7	11/08/91 01:00 PM	40.38	48.03	47.62	0.67	1.18	84.06			3.78	12.15
8	11/08/91 02:00 PM	40.85	48.77	47.16	0.68	1.15	83.76			3.78	12.31
9	11/08/91 03:00 PM	39.99	48.99	47.61	0.67	1.19	81.64			3.61	12.22
10	11/08/91 04:00 PM	40.39	49.38	48.46	0.68	1.20	81.79			3.58	12.34
11	11/08/91 05:00 PM	30.47	40.15	31.33	0.55	1.03	75.88			3.28	9.88
12	11/08/91 06:00 PM	13.81	22.57	16.26	0.29	1.18	61.22			2.73	4.73
13	11/08/91 07:00 PM	9.25	16.91	11.20	0.21	1.21	54.74			2.42	3.28
14	11/08/91 08:00 PM	7.85	14.95	9.51	0.19	1.21	52.53			2.29	2.84
15	11/08/91 09:00 PM	7.28	14.18	8.87	0.18	1.22	51.32			2.25	2.66

RESULTS / HELP INFORMATION / AIR FREE / CH4 FREE / FLAMMABILITY DATA / RATIOS / EXPLOSIBILITY ASSESSMENT / GRAHAM'S YOUNG'S RATIOS

Fig. 4 – Typical display of ratios trended using SMARTMATE

CONCLUDING COMMENTS

A Mines Rescue Manager must ensure that an accurate and reliable assessment of the atmosphere underground has been made prior to any decision making process being undertaken to deploy Mines Rescue Brigadesmen underground. The Emergency Preparedness and Mines Rescue Guidelines provide guidance to Incident Management Teams and Mines Rescue Officers in regards to their responsibilities in this area.

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