

OUTBURST THRESHOLD LIMITS – ARE THEY APPROPRIATE?

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ABSTRACT

The 1994 outburst threshold limits imposed on coal mines operating in the Bulli seam were lower than the conservative value proposed by Lama in 1991. Equally conservative is the DRI900 method for outburst threshold limit determination. A number of mines have encountered areas where it has been difficult, if not impossible, to reduce the seam gas to below the prescribed threshold limit prior to the arrival of roadway development machinery, despite extensive in-seam gas drainage. In such situations these mines can experience lengthy production delays or even loss of reserves. Several Bulli seam mines have completed reviews of their outburst risk management which led to increasing their threshold limits. These mines have been operating safely, without outburst, for some four years. The method of determining the outburst threshold limits applicable to non-Bulli seam coal mines also hold a high degree of conservatism which is discussed. The need for re-appraisal of the threshold limits undertaken is reported, based on the further data analysis. The process of gas desorption methodology and the optimum gas content is one particular aspect of this study as it has a clear influence on the established values of the recognised threshold limits. The study has demonstrated that there is justification to increase the operating threshold limits to values of 12 m³/t for 100% CH₄ and 8 m³/t for 100% CO₂. Research is continuing to include sample analysis from other Australian mines.

INTRODUCTION

The first recorded outburst of coal and gas occurred in the Bulli seam at the Metropolitan Colliery was on 30th September 1895. Since then there has been some 669 outburst events recorded in Australian underground coal mines, 449 in the Bulli seam of the Illawarra coal measures and more than 220 in the Bowen Basin (Lama and Bodziony, 1998). Various theories have been presented regarding the factors that contribute to the occurrence of coal and gas outbursts. A summary list of factors that have generally been accepted as having the potential to contribute to an outburst is given by Lama (1995):

1. Tensile strength of coal
2. Gas emission rate
3. Gas pressure gradient
4. Moisture level
5. Depth or stress level

Previous studies have concluded that in the Bulli seam stress does not play a significant role and it is gas which is the major contributing factor to outburst occurrence. The use of gas drainage to reduce seam gas content levels to a value considered safe for mining has been uncritically accepted by the mining industry. The factors that are considered to impact upon outburst propensity have been incorporated to provide an assessment of outburst risk condition, shown in the outburst risk matrix in Figure 1.

Virtually all of the outbursts that have occurred in the Bulli seam have been associated with geological structures and been located in areas where no substantial gas drainage has been undertaken. There have been 12 outburst related fatalities in Bulli seam mines (Harvey, 1995) all of which occurred in areas without any gas drainage and where carbon dioxide was the primary seam gas component (Lama, 1995).

Following the last outburst related fatality, which occurred at West Cliff Colliery on 25th January 1994, the NSW Department of Mineral Resources (DMR) issued a directive to all Bulli seam mine managers detailing actions to be implemented at their mines. Arguably the most significant of these actions was the stipulation of limits on seam gas content prior to mining, known as threshold limits and shown graphically in Figure 2A. The introduction of the threshold limits resulted in a significant increase in the intensity of drilling and gas drainage in these mines for the purpose of structure identification and gas content reduction. Operators developed comprehensive outburst management plans which included standard drilling patterns and routine management controls to deal with the issue of gas content reduction. Subsequently outburst threshold limits have been adopted by all Australian mines and in the majority of cases these controls have proven successful, with the exception of two small outbursts. These two outbursts occurred in Bowen Basin mines, at Central Colliery on 20th July 2001 and at North Goonyella Mine on 22nd October 2001.

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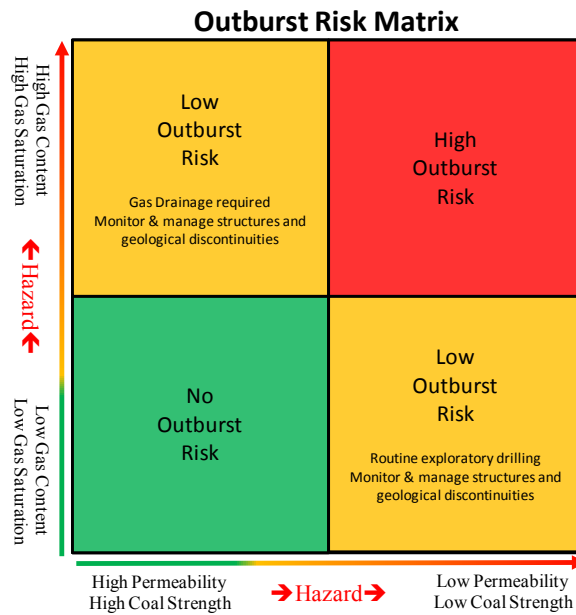


Figure 1: Outburst risk matrix

Following the introduction of the outburst threshold limits and the virtual elimination of outburst occurrence from the Australian coal industry there has been a sharp decline in the research effort directed toward improved understanding of the outburst phenomenon.

With the ever increasing production capacity of mining equipment, mine operators are endeavouring to produce at much faster rates and in many cases the conventional gas drainage management techniques are struggling to achieve sufficient gas content reduction ahead of the advancing mine development. In such situations the typical response of operators has been to increase the density of boreholes through infill drilling to reduce the spacing between boreholes, however this may not be sufficient and production delays may still result. If not effectively managed it is possible that gas drainage may provide very little benefit and it is therefore important to monitor and understand the behaviour and performance of the gas drainage system to enable problems to be identified and appropriate corrective action taken where necessary (Black and Aziz, 2008). In extreme cases operators have chosen to sacrifice coal reserves in favour of redirecting mining effort to areas with more favourable drainage response. Recently both Tahmoor and West Cliff Collieries have completed formal reviews of their respective outburst threshold limits which supported increasing the threshold limits. The revised threshold limits for these two collieries are shown graphically in Figure 2B. Several other Bulli seam mines are now considering, or in the process of, reviewing threshold limits.

It is important to note that the lack of outburst incidents, although positive for the industry, has prevented the collection of outburst related experience and data necessary to improve the technical understanding of the outburst phenomenon. Therefore to a large degree the threshold limit reviews are underpinned by qualitative risk assessment and lack detailed technical assessment. The Gas Research Group (GRG) at the University of Wollongong is presently conducting a number of projects to improve the industry's understanding of gas storage, transport and drainage characteristics the results of which will support quantitative assessment of outburst risk.

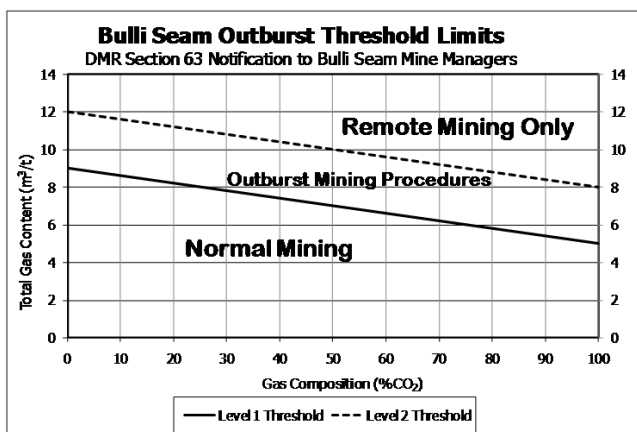


Figure 2A: DMR specified outburst threshold levels

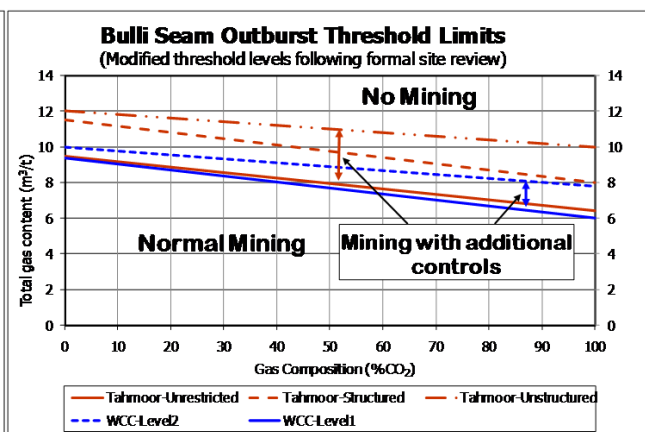


Figure 2B: Revised thresholds – West Cliff and Tahmoor

BULLI SEAM OUTBURST THRESHOLD LEVELS

In 1995 Lama provided a description of the process that led to his 1991 recommendation of threshold levels applicable to Bulli seam mines. Lama suggested that where structures exist, within a zone of 2.5 metres from the mine workings, the 'desorbable' gas content should be less than a threshold limit of 8.0 m³/t (100% CH₄) to 4.0 m³/t (100% CO₂) and in all other areas, free of structures, the 'desorbable' gas content should be less than a threshold limit of 10.0 m³/t (100% CH₄) to 7.0 m³/t (100% CO₂). Lama acknowledged that these limit values were somewhat conservative to account for what was considered to be a high rate of development advance, up to 75 m/day.

In reviewing the methodology used by Lama it is apparent that the proposed outburst threshold limits were essentially based on previous operating experience in the Bulli seam, and the inferred gas content and composition of the seam gas present in areas where outbursts had occurred. The fact that there had been no recorded outbursts where the gas content was known to be less than the proposed threshold limits supported the proposal.

Recent slow desorption testing conducted by the GRG has demonstrated that gas will continue to desorb from coal samples in slow desorption testing for a period well beyond 12 months. Therefore should the testing undertaken by Lama have not been afforded sufficient time to completely liberate the 'desorbable' gas content, then the gas content levels measured would be understated by several cubic metres per tonne and the actual values should be greater than those presented.

In order to determine whether the gas content within the coal seam in a particular area is below the prescribed threshold limit, coal samples, typically core samples, are collected for analysis. There is a need for mine operators to obtain gas content and composition data from coal samples as quickly as possible, to determine if an area is 'below threshold' and therefore considered safe to allow mining to continue or otherwise 'above threshold' and therefore requiring additional action to further reduce gas content.

The fast desorption method of gas content measurement, as described in AS3980, is the method accepted and employed by the Australian mining industry. The fast desorption method of gas content measurement does however determine the 'total' gas content of a coal sample, which is greater than the desorbable gas content. Lama (1995) acknowledges the need for the 1991 proposed threshold limits to be changed to reflect outburst threshold limits based on 'total' gas content. The process used by Lama to determine 'total' gas content outburst threshold limits was to determine the 'residual' gas content for both high CO₂ and high CH₄ coal seam gas conditions and simply add these measured values to the previously stated 'desorbable' gas content threshold values as (Equation 1).

$$\text{Total Gas Content (m}^3/\text{t)} = \text{Desorbable Gas Content (m}^3/\text{t)} + \text{Residual Gas Content (m}^3/\text{t)} \quad (1)$$

In determining the value of residual gas content for both high CH₄ and high CO₂, to be added to the desorbable gas content threshold limits, Lama simply averages the mean residual gas content values determined from four separate tests. The test results reported by Lama have been reproduced and presented in Table 1. Lama acknowledges that in the case of the residual gas content determined for CO₂ in laboratory testing of dry coal samples the measured value is unacceptably high and the reported result was halved to achieve a more appropriate value for inclusion in the averaging exercise. It should also be noted that the reported residual gas content for CH₄ is greater than CO₂ for both the underground and surface borehole sampling, which is contrary to accepted gas sorption theory.

Table 1: Residual gas content in Bulli coal samples (after Lama, 1995)

METHOD	MEAN RESIDUAL GAS CONTENT (cc/g)		
	CH ₄	CO ₂	CO ₂ *
Laboratory sorption (DRY)	2.21	6.76	3.38#
Laboratory sorption (MOIST)	1.67	3.72	3.72
U.G. Sampling	2.01	1.96	1.96
Surface borehole sampling	2.13	1.09	1.09
Other independent labs. (UG sampling from KCC operations)	2.00	2.90	2.90
COMBINED MEAN VALUE	2.00	3.29	2.61

* Test results have been modified

Value half of the result obtained from testing

From this method Lama reports the residual gas content values to be added to the previously proposed 'desorbable' gas content limits of 2.01 m³/t (100% CH₄) and 2.4 m³/t (100% CO₂).

Therefore the outburst threshold values, representing ‘total’ gas content are as follows:

1. Within a zone 2.5 m either side of a structure the ‘total’ gas content should be less than a threshold limit of 10.0 m³/t (100% CH₄) to 6.4 m³/t (100% CO₂); and
2. In all other areas, absent of structures, the ‘total’ gas content should be less than a threshold limit of 12.0 m³/t (100% CH₄) to 9.4 m³/t (100% CO₂).

Recent testing of Bulli seam coal samples by the GRG has determined that, in the case of sorption testing at normal temperature and pressure (NTP) conditions, the residual gas content was in the order of 0.87 m³/t for 100% CH₄ and 1.98 m³/t for 100% CO₂, and in the case of slow desorption testing, the residual gas content ranged between 0.63 m³/t and 1.8 m³/t. These results support Lama’s acknowledgement that insufficient desorption time was allowed prior to residual gas content testing and the values presented in Table 1 are likely to be somewhat overstated.

Based on the Section 63 directive from the DMR it appears that an additional ‘factor of safety’ was applied to the gas content threshold values as the limits imposed on Bulli seam mines was less than the limit values proposed by Lama. It also appears that allowance was not made for the introduction of intensive in-seam gas drainage drilling and the impact on structure and therefore outburst risk identification.

As shown in Figure 2B both West Cliff and Tahmoor Collieries have completed formal reviews of their respective outburst management process which resulted in their receiving approval to increase outburst threshold limits. Both mines have been operating with the increased threshold limits in place for some four years whilst remaining free of outburst.

NON-BULLI SEAM OUTBURST THRESHOLD LEVELS

In 1995 Williams and Weissman presented the concept of using gas desorption rate as a means to determine applicable outburst threshold limit values for coal mines operating in coal seams other than the Bulli seam. Underpinning this desorption rate proposal was an apparent relationship with the Bulli seam threshold limit values previously proposed by Lama, shown in Figure 3. The test involves measuring the volume of gas emitted from a 200 gram sub-sample of coal core sample after crushing for 30 seconds and relating the result to the total gas content of the full core sample. As shown, the data presented, which represents samples with gas composition >90% CH₄ and >90% CO₂, indicates that at the proposed threshold values of 9 m³/t (100% CH₄) and 6 m³/t (100% CO₂) a common desorbed gas volume of 900 ml is liberated. It was therefore concluded that the total gas content which corresponds to a gas desorption of 900 ml represents the outburst threshold limit applicable to that coal mine. This method, known as DRI900, has been uncritically accepted by the mining industry for determining outburst threshold limit values applicable to non-Bulli seam mines.

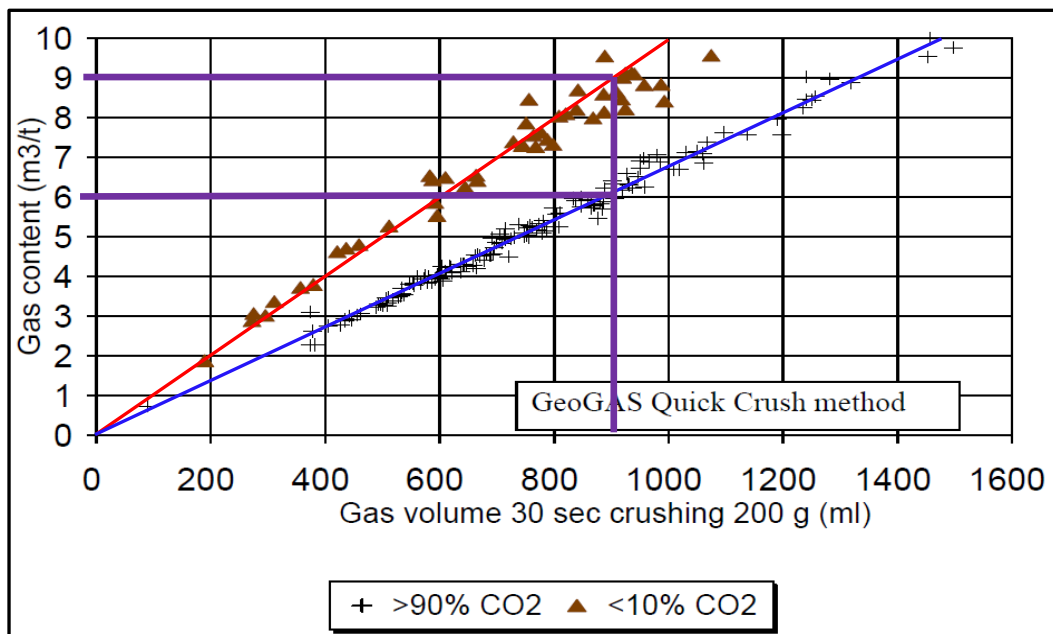


Figure 3: GeoGAS desorption rate (DRI900) relative to Lama’s outburst threshold limit values

Given the potential for Lama’s proposed threshold levels to be somewhat conservative it is possible that the DRI900 value may be somewhat conservative and therefore understate the appropriate outburst threshold limit in non-Bulli seam mines. This is further supported by the fact that two Bulli seam mines have been successfully operating at threshold limits greater than those upon which the concept was originally based.

Consider a situation where state of the art drilling and data collection technology is employed at a Colliery as part of routine in-seam gas drainage drilling and that this technology is capable of identifying geological structures and other anomalies as well as draining seam gas. In such a Colliery, operating in the Bulli seam, it is considered reasonable, given the previous work of Lama and the recent experience at Tahmoor and West Cliff, that a threshold limit of 12 m³/t (100% CH₄) and 8 m³/t (100% CO₂) is not unreasonable in areas free of structures. Applying this threshold limit to the gas desorption dataset presented by Williams and Weissman, a DRI of 1200 is indicated (Figure 4).

Given the potential for the DRI900 concept to be understating outburst threshold limits in non-Bulli seam coal mines further investigation was undertaken to validate the Gas Desorption / Gas Content relationship used by Williams and Weismann (1995). Core sample gas content and composition data was obtained from two Bulli seam Collieries and analysed to enable direct comparison to the GeoGAS data. The results from this analysis show that in the case of Mine A the average gas desorption / gas content relationship is independent of gas composition and both the >90% CH₄ and >90% CO₂ trend lines have a similar gradient, which are also similar to the GeoGAS >90% CO₂ trend line. The data from both Mine A and B, within the gas content and gas desorption ranges presented by Williams and Weissman, is shown in Figure 5. The gas data from Mine B shows the trend line for >90% CH₄ is also similar to the CH₄ and CO₂ results from Mine A and the CO₂ results from GeoGAS. The Mine B >90% CO₂ trend line however has a higher gradient, which is the result of increased early stage desorption from samples with higher total gas content. The complete data set from both Mine A and Mine B, incorporating the GeoGAS datasets is shown in Figure 6. The Mine B data indicates that for >90% CO₂, below approximately 7.5 m³/t (total gas content), the average gas desorption / gas content trend line is approximately equal to the >90% CH₄ trend line.

It can be concluded from the analysis of 930 core samples representing a broad range of gas content and composition conditions within two Bulli seam mines, that the gas desorption / gas content is, to a large degree, independent of gas composition.

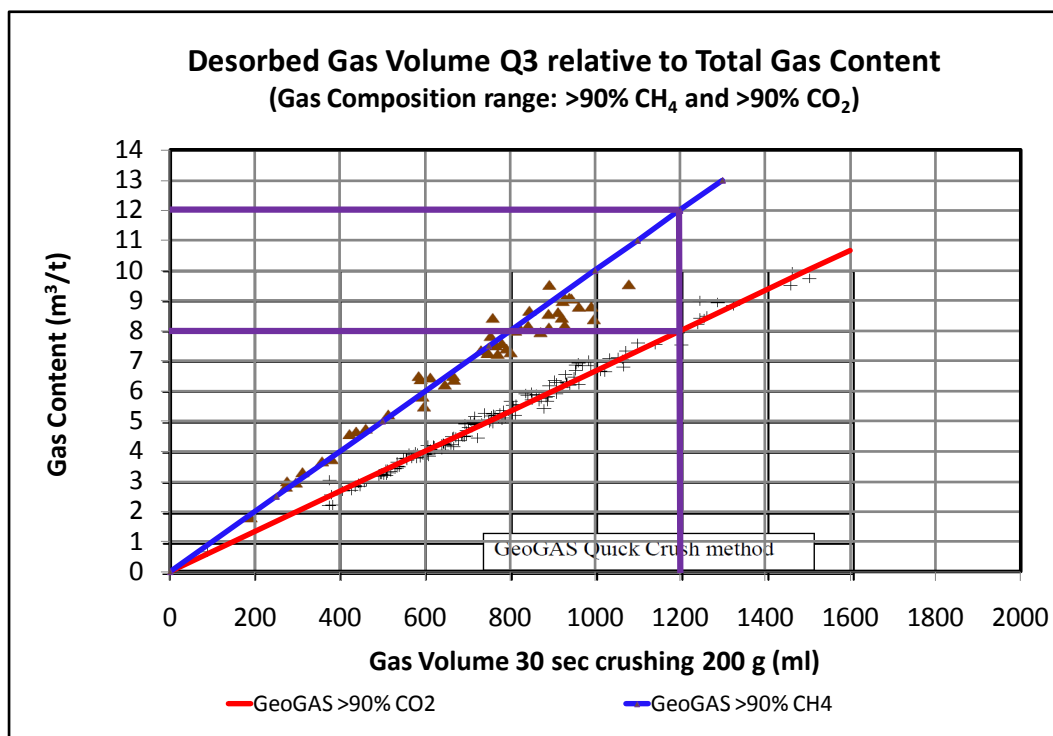


Figure 4: DRI1200 indicated for potential Bulli seam outburst threshold limits in non-structured areas

**Desorbed Gas Volume Q3 relative to Total Sample Gas Content
(Bulli A & Bulli-B UIS Core Analysis and GeoGAS DRI Background Data)
(Gas Composition range: >90% CH₄ and >90% CO₂)**

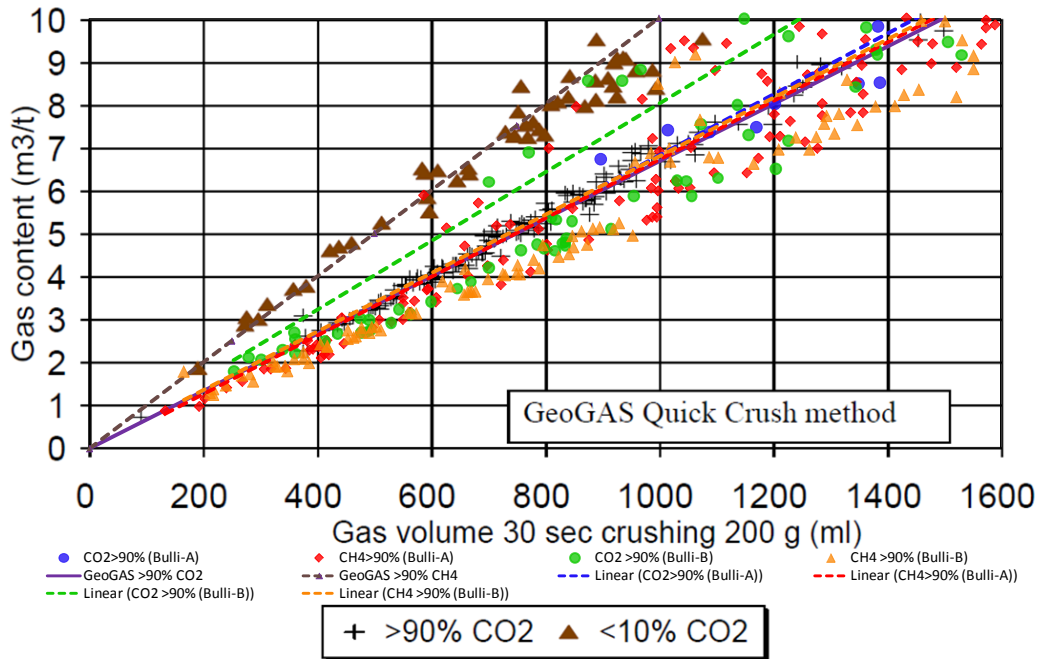


Figure 5: Mine A and Mine B gas desorption / gas content data relative to Williams & Weissman (1995) data

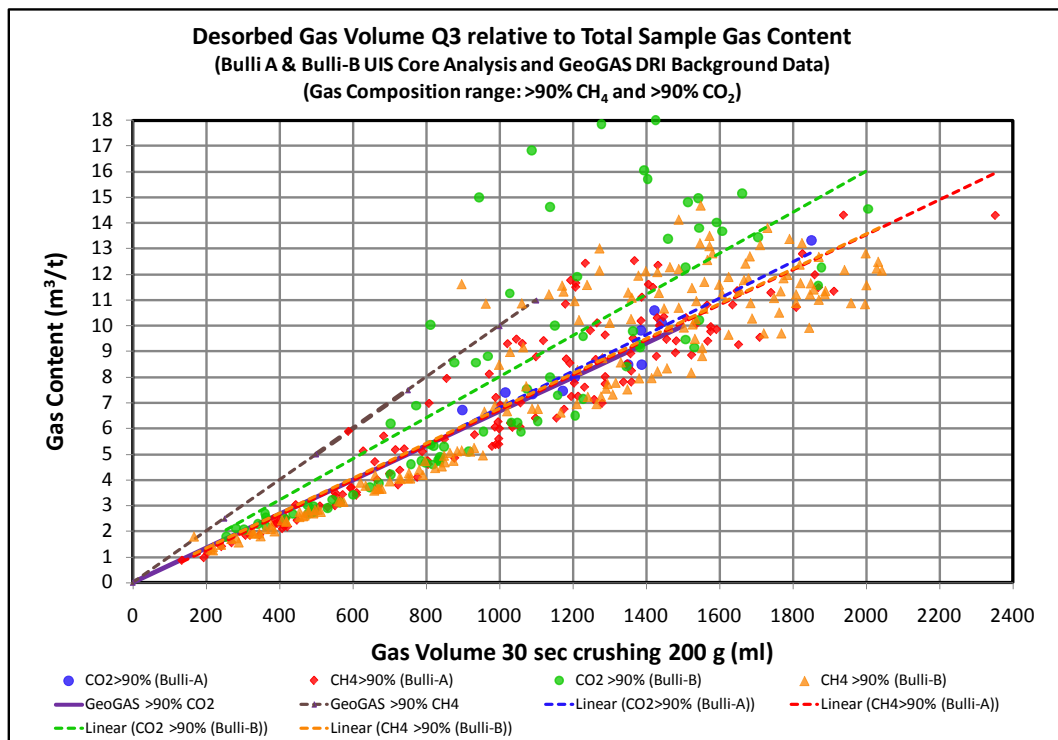


Figure 6: Complete Mine A and B gas desorption / gas content data (930 points) relative to Williams & Weissman (1995) data

Considering the data presented in both Figures 5 and 6, as the basis for determining the desorption rate, which is applicable to the Bulli seam for given outburst threshold limits, it can be concluded that particularly in the case of CH₄, the desorbed gas volume will be somewhat higher than a DRI of 900 and will likely be somewhere in the range of 1400 to 1800, depending on the actual gas content threshold limit.

Additional data is now being sought from other Bulli and Non-Bulli seam coal mines to further investigate and analyse the extent of the gas desorption relationships which exist both within and between coal seams.

CONCLUSIONS

This analysis provides an interpretation of the process which led to the specification of outburst threshold limits applicable to mines operating in the Bulli seam of New South Wales. Given the work reported by Lama, it is evident that these threshold limits were potentially very conservative and incorporated quite high factors of safety. Given the loss of life resulting from outburst at the time and the general lack of understanding of the outburst phenomenon implementing conservative thresholds was assured of preventing further outburst related fatalities. This conservative approach to outburst threshold determination has also been applied to non-Bulli seam mines through the use of the GeoGAS DRI900 methodology.

In the fourteen years following the specification of outburst threshold limits there have been no reported outbursts in mines operating in the Bulli seam, where the gas content has been reduced to below the prescribed threshold limit. Two Bulli seam collieries have completed formal reviews of their respective outburst risk which resulted in increasing their threshold limits. Both Collieries have been operating safely, without outburst, for some four years under the increased threshold limits.

Gas is accepted as the primary risk factor associated with outburst and it is for this reason that gas drainage will for the foreseeable future be an integral part of outburst risk control and management. However unless properly controlled and managed it is possible for gas drainage to be quite ineffective.

Therefore the effective and efficient drilling and removal of gas from coal seams ahead of mining not only supports increased outburst threshold levels but also offers benefits such as reduced production delays, increased utilization of available coal reserves, reduced gas loading of mine ventilation air and, if suitable reticulation and utilisation facilities exist, reduced greenhouse gas emissions.

More research is required to improve the industry's understanding of the mechanisms that control gas storage, transport and drainage from coal, not only to better understand and manage the outburst risk, but for further improvement of mining related gas emissions reduction both into the ventilation network and into the environment.

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