# ANALYSIS OF BULLI SEAM BENCHMARK AND DRI TO DETERMINE OUTBURST THRESHOLD LIMITS

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*ABSTRACT:* Following the introduction of the Desorption Rate Index (DRI) and Bulli Seam Benchmark to the Australian coal industry in 1995, the use of the DRI900 method was adopted and continues to be used as the primary method to assess outburst risk and to determine gas content threshold values for outburst risk management in Australian coal seams. In addition to assessing outburst risk based on gas content threshold values, several Australian coal mines also include DRI900 as a threshold level in assessing outburst risk. It is apparent that there is a broad lack of awareness and understanding of the limitations and deficiencies of using DRI to assess outburst risk and to determine appropriate outburst threshold limit values.

A comprehensive set of gas test results from Australian coal seams has been collected as part of research into control and management of outburst risk in Australian underground mines and the results of specific investigation into DRI and its applicability for use in assessing outburst risk and determining appropriate gas content threshold levels has identified significant deficiencies which are presented and discussed.

## BACKGROUND

Following the fatal outburst that occurred at West Cliff colliery on 25 January 1994, the NSW Department of Mineral Resources issued a directive to operators of Bulli seam mines, which among the required actions intended to improve the management of outburst risk, specified gas content threshold limit values (TLV) for normal and outburst mining. As shown in Figure 1, the prescribed TLV for 'normal' mining was 9.0 $m^3$/t in 100% $CH_4$ conditions and 5.0 $m^3$/t in 100% $CO_2$ conditions and the TLV for 'outburst' mining was 12.0 $m^3$/t in 100% $CH_4$ conditions and 10.0 $m^3$/t in 100% $CO_2$ conditions.
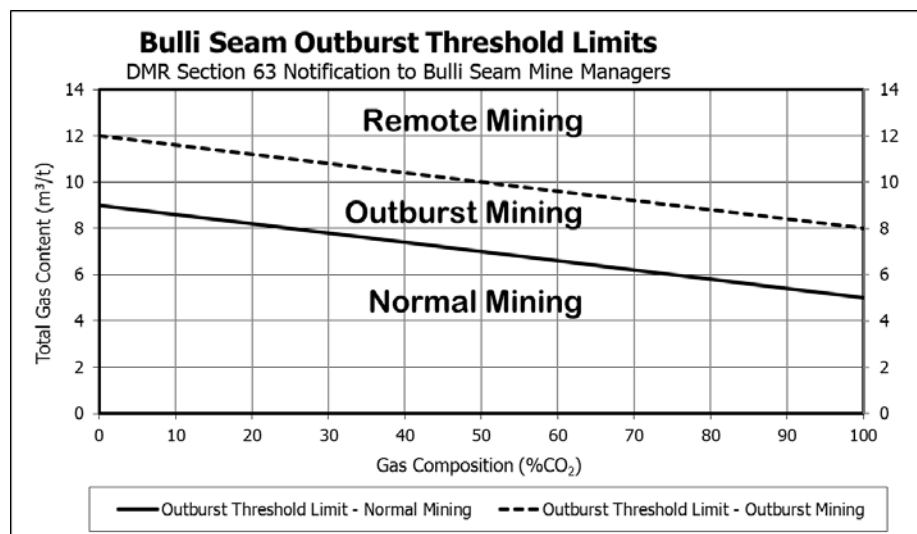


Figure 1 – DMR specified Bulli seam outburst threshold limit values

Williams and Weissman (1995) presented a relationship between total measured gas content (QM) and a new term they referred to as Desorption Rate Index (DRI). The relationship between QM and DRI, which they had identified from analysis of gas emission data during gas content testing of core samples sourced from West Cliff colliery that contained high concentrations of $CH_4$ and $CO_2$, is presented in Figure 2. The data indicates a linear relationship between QM and DRI, represented by the equation, $QM = \alpha.DRI$, where the variable gradient of the trendline, $\alpha$, representing the average of the data points, equals 0.01 for >90% $CH_4$ and 0.0067 for >90% $CO_2$. This relationship between QM and DRI, identified from testing Bulli seam coal samples sourced from West Cliff colliery, was referred to as the Bulli Seam Benchmark. The relationship was assumed by Williams and Weissman (1995) to be representative of all Bulli seam conditions.

It was reported that the test to determine DRI involved measuring the volume of gas emitted from a 200 g sub-sample of coal material after crushing for 30 seconds and extrapolating the result to the total gas content (QM) of the full core sample to determine the DRI of the full coal sample (Williams, 1996 and Williams, 1997). The process to determine DRI, presented graphically by Williams (1997) is shown in Figure 3.

Using the Bulli Seam Benchmark, Williams and Weissman (1995) reported that gas content values of 9.0 $m^3$/t for $CH_4$ rich coal and 6.0 $m^3$/t for $CO_2$ rich coal, both corresponded to a common DRI value equal to 900 (Figure 4). They further

proposed that, subject to determining the average gradient ($\alpha$) of the QM-DRI relationship for a given coal seam, the QM value corresponding to a DRI of 900 represents the applicable outburst TLV for that coal seam. Figure 5 illustrates the method used to determine the equivalent outburst gas content TLV using the equation $QM = \alpha \cdot 900$, where $\alpha$ is determined for each coal seam. Mining in areas where the gas content level has been reduced below this threshold is intended to result in zero gas dynamic incidents and outbursts, regardless of the severity of any other condition (e.g. stress, degree of faulting, rate of mining).
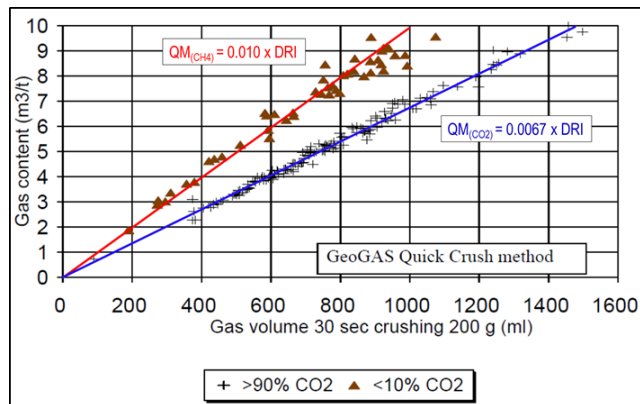


Figure 2: QM-DRI data presented for CH4 and CO2 samples from West Cliff colliery (Williams and Weissman, 1995)
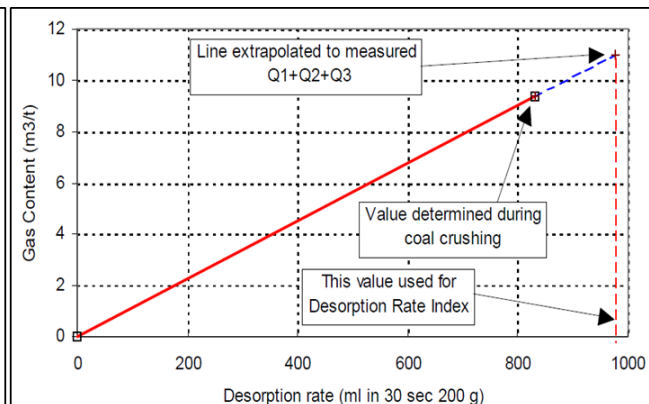


Figure 3: Method used to calculate DRI from gas emission recorded during Q3 crushing (Williams, 1997)
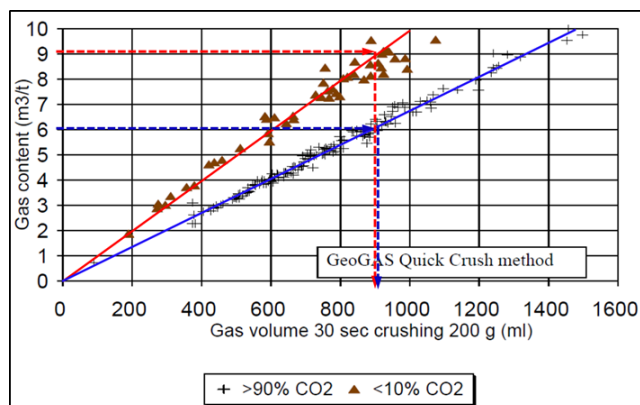


Figure 4: Bulli Seam Benchmark indicating DRI900 corresponding to 9.0 m³/t (CH4) and 6.0 m³/t (CO2)
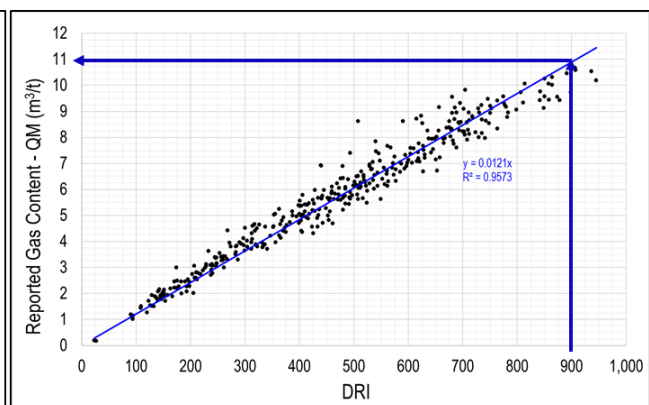


Figure 5: Method using DRI900 to determine outburst gas content TLV for a coal seam using the QM-DRI relationship

Recent investigation and analysis of gas test data sourced from Australian coal seams, including the Bulli seam, has confirmed the two input variables required to calculate DRI are (a) the volume of gas released from a sub-sample of core in the initial 30 seconds after crushing during the Q3 phase of gas testing, adjusted to a standard sample mass of 200 g (Q3(30s)), and (b) the relative percentage of QM reported as Q3 (Q3/QM). As DRI is effectively a measure of the rate of gas release during mechanical crushing of coal it is considered that it is incorrect and not appropriate to imply that DRI is a measure of desorption rate.

There has been increasing concern that DRI is overly simplistic and not a valid measure to fully assess and quantify outburst risk. Australia is the only country that uses a measure of gas emission from crushed coal as the basis for establishing outburst risk. China, Russia and other European countries employ measures of gas emission rate from fresh coal, during initial gas desorption. Examples of these measures of initial gas desorption used to assess outburst proneness include: ΔP, ΔP$_{0-60}$, ΔP Express, K$_T$ Index, V30 and V Index, which effectively are measures of gas pressure or gas volume release from small sized particles collected in advance of working faces all of which aim to measure and compare gas emissions in the early stages of gas desorption from coal samples (Lama and Bodziony, 1996).

With reference to current Australian standards and practice, Initial Desorption Rate (IDR30) is a measure of the volume of gas desorbed from coal in the initial 30 minutes following collection of the core. IDR30 is routinely reported as part of gas content testing in accordance with Australian Standard AS3980:2016. Limited work has been undertaken to date to investigate the use of IDR30 as a potential indicator of outburst risk.

Another critical factor that impacts outburst risk is coal strength / coal toughness, and the ability of the coal to remain intact and avoid sudden brittle tensile failure due to mining induced fracturing and applied gas pressure. As the majority of outbursts that have occurred in Australian underground coal mines have been associated with geological structures, the impact and increased risk of outburst associated with structures must be considered.

The current ACARP funded research project (C26055) is investigating the relevance and applicability of the Bulli Seam Benchmark and DRI for use in assessing outburst risk and determining appropriate outburst threshold gas content values for Australian underground coal mines.

## BULLI SEAM BENCHMARK

Raw gas emission data collected during gas testing on coal samples collected from areas of the Bulli seam rich in both CH4 and CO2 seam gas has been analysed to investigate the current Bulli Seam Benchmark and to determine whether the nature of gas emission from current mining areas has shifted from the original data presented in 1995 (Williams and Weismann, 1995). Figure 6 shows the relationship determined from the Bulli seam data collected to date. The results show a shift in the QM-DRI relationship for both CH4 and CO2, compared to the 1995 relationship, with increased DRI values relative to gas content.

Using records of gas emission during Q3 testing, the DRI calculation was repeated using the gas volume liberated from coal samples after the initial 60 seconds of crushing during Q3 testing, DRI(60s). The QM-DRI(60s) relationship for CH4 and CO2, presented in Figure 7, highlights the effect of increased gas volume release in the initial 60 seconds compared to the initial 30 seconds of Q3 crushing. Considering the extreme case of 100% of recorded Q3 gas emission being released from the coal samples within the initial 30 seconds of Q3 crushing, for both CH4 and CO2 rich coal samples, the resulting QM-DRI relationship is shown in Figure 8. This analysis confirms the significant impact and sensitivity that the measurement of gas volume released from coal samples during crushing has on the DRI.
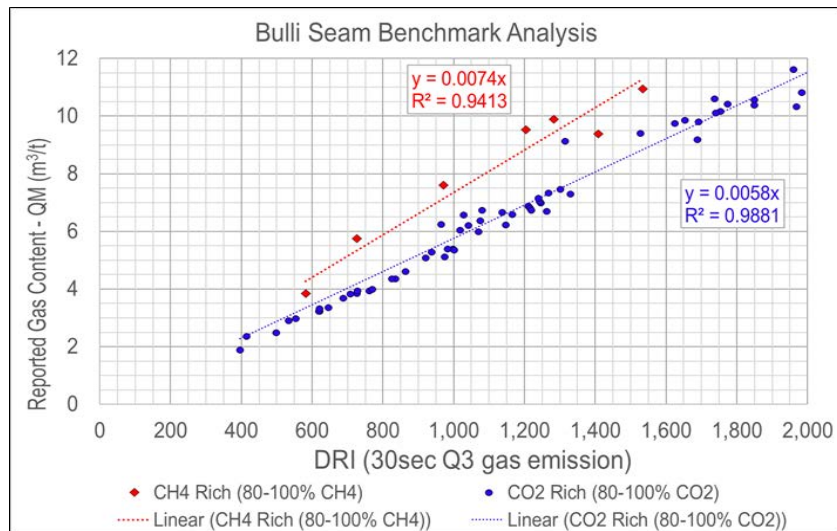


Figure 6 – Results of 2017 analysis of Bulli Seam Benchmark relationship for CH4 and CO2 rich coal samples
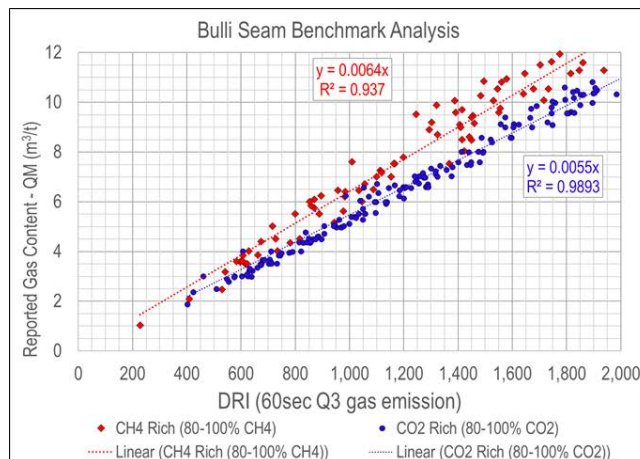


Figure 7: Relationship between QM and DRI calculated using gas volume emitted in first 60 seconds of crushing during Q3 (DRI60) for CH4 and CO2 rich coal samples.
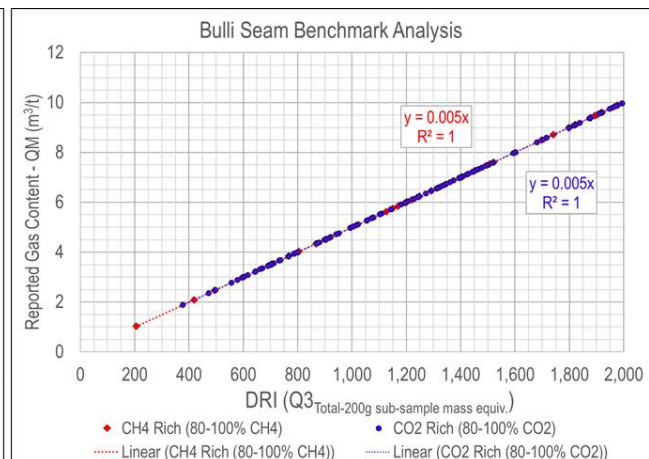
Figure 8: Relationship between QM and DRI, where DRI is calculated based on 100% of gas emission during Q3 testing of a 200g coal sample occurs in the initial 30 seconds of crushing.

The investigation of gas data collected during 2017 indicated a change in Bulli Seam Benchmark relationships for both CH4 and CO2 rich coal samples, presented in Figure 6, compared to the 1995 relationship presented in Figure 2. Given the impact that crushing efficiency and rate of gas release during Q3 has on DRI, a direct comparison of Q3 gas emission from two similar coal samples tested at different laboratories confirmed a difference in crushing efficiency and rate of gas release, shown in Figure 9. Further investigation also confirmed differences in crushing equipment used at two separate gas test laboratories. As shown in Figure 10 and Figure 11 respectively, Lab 1 uses twin puck and Lab 2 uses a single puck arrangement in the bowls of their ring mill crushers.

Analysis of the recorded gas emission from CH4 and CO2 rich coal subsamples weighing approximately 200 grams, after crushing in the Lab 1 ring mill for 30 seconds, confirmed initial gas flow rate from CO2 rich coal was consistently faster than from CH4 rich coal. Figure 12 and Figure 13 show the impact of seam gas composition on the percentage of Q3 gas content released from crushed coal samples in the initial 30 seconds (Q3(30s)/Q3) and the initial 60 seconds (Q3(60s)/Q3) of flow measurement. For CH4 rich coal samples, QM ranging from 4.0 to 11.0 $m^3/t$, Q3(30s)/Q3(Total) varied between 64

to 74% whereas for CO2 rich coal samples, QM ranging between 2.0 and 17.0 m³/t, except for one sample, Q3(30s)/Q3(Total) varied between 83 to 95%.
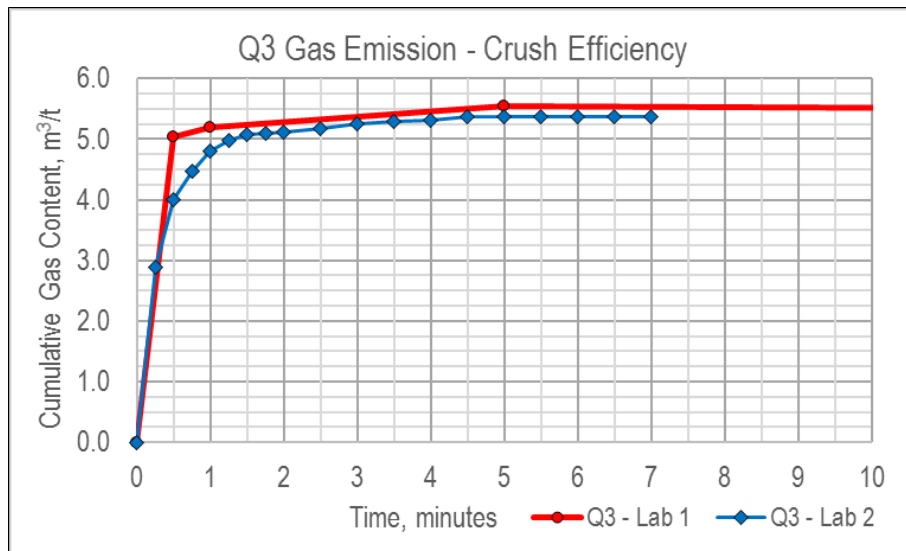


Figure 9 – Laboratory comparison of gas release rate during Q3 crushing indicating difference in crushing efficiency



Figure 10: Lab 1 – twin puck ring mill Q3 coal crusher bowl.



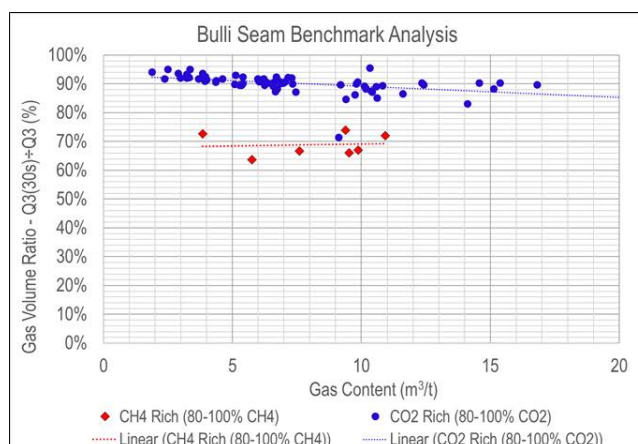Figure 11: Lab 2 – single puck ring mill Q3 coal crusher bowl.



Figure 12: Percentage of Q3 gas release in first 30 seconds of crushing CH4 and CO2 rich coal (Q3(30s)/Q3) presented relative to sample QM.
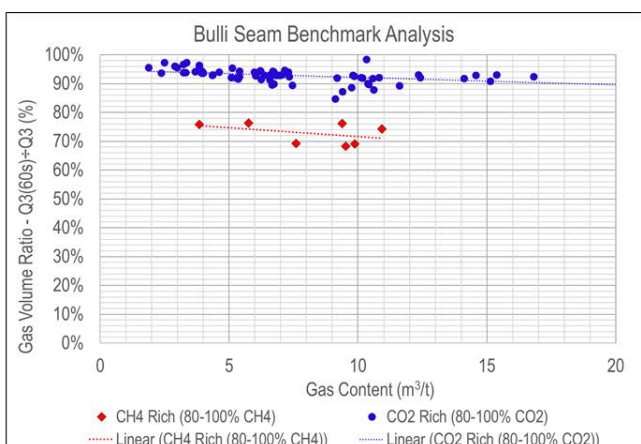


Figure 13: Percentage of Q3 gas release in first 60 seconds of crushing CH4 and CO2 rich coal (Q3(60s)/Q3) presented relative to sample QM.

Further investigation of gas emission data from CH4 and CO2 rich coal samples that impact the DRI calculation (a) volume of gas released from crushed coal in the initial 30 seconds of Q3 gas content testing (Q3(30s)), and (b) percentage of total gas content recorded as Q3 (Q3/QM), are presented in Figure 14 and Figure 15. The data shows that, for a given gas content (QM), (a) the volume of gas released in the initial 30 seconds of Q3 crushing from CH4 rich coal is less than from CO2 rich coal, and (b) the volume of gas measured during Q3 (Q3/QM) tends to be greater in CH4 rich coal, indicating a larger component of QM is released during the Q1 and Q2 stages of gas content testing from CO2 rich coal.
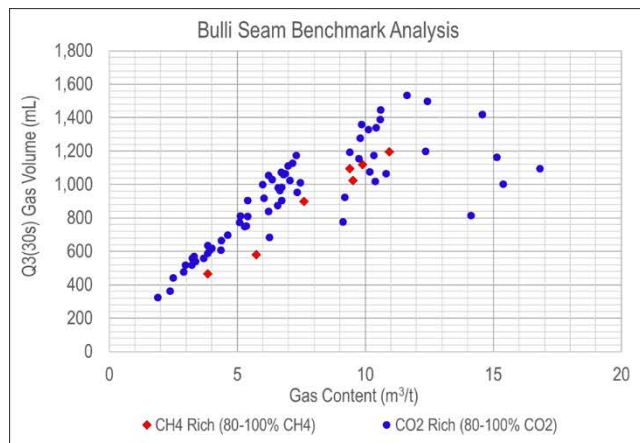
Figure 14: Gas volume released in initial 30 second of Q3 crushing from CH4 and CO2 rich coal samples relative to QM.
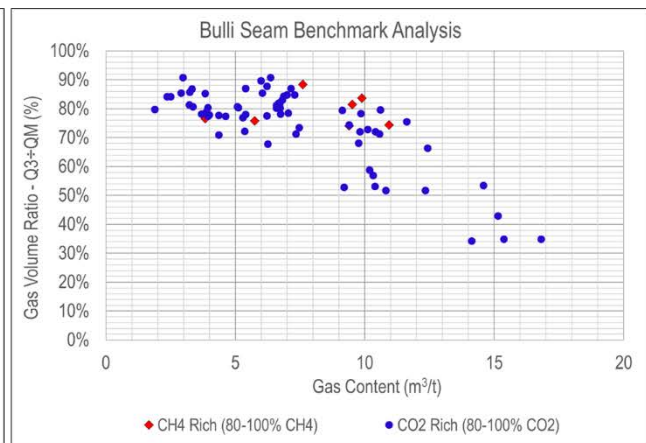
Figure 15: Percentage QM recorded as Q3 during gas testing CH4 and CO2 rich coal samples relative to QM.

## DESORPTION RATE INDEX – DRI

Using the DRI approach to assess outburst proneness was regarded by Williams (2002) as being directly related to the desorption rate of the coal. However, the investigation of Bulli Seam Benchmark has shown that DRI is extremely sensitive to small changes in gas testing procedures, in particular (a) the time when the Q2 phase of gas testing is concluded, (b) time to break core and prepare subsamples of core material for use in Q3 testing, and (c) the equipment and energy applied to crush the coal during Q3 testing. Other potential limitations in the use of DRI to assess outburst risk and the use of DRI900 to determine outburst threshold levels has been investigated.

Figure 16 presents results from gas content testing on coal core samples collected from a CH4 rich non-Bulli seam mine, which includes the reported gas content component values, Q1, Q2 and Q3, IDR30 and DRI for core samples ranging in gas content from 3.0 to 14.1 $m^3$/t. The graph shows DRI closely aligns with QM, whereas variability in Q1 and IDR30 does not have any impact on DRI.
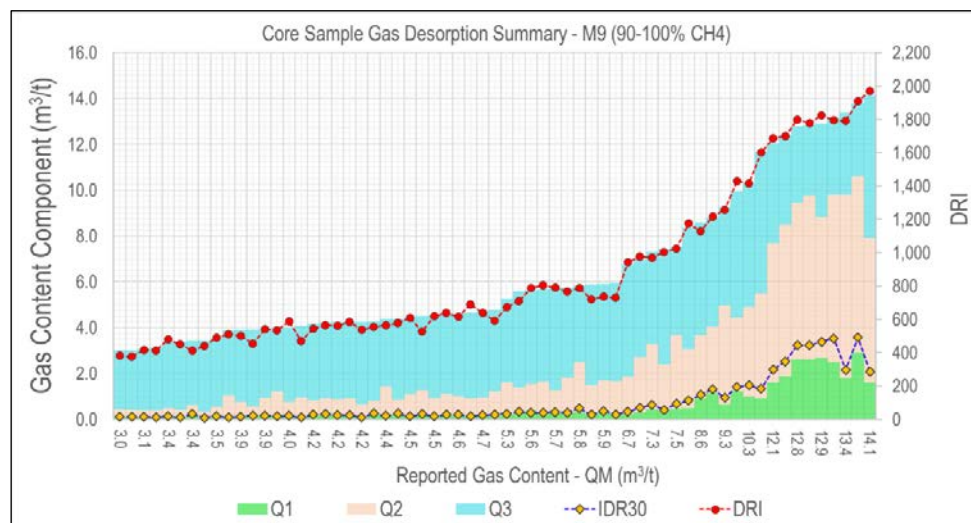


Figure 16 – Sample of reported gas test data and DRI sourced from a CH4 rich, non-Bulli seam mine (M9)

Figure 17 presents a comparative analysis of 21 core samples with gas content (QM) = 10 $m^3$/t, to show the impact that (a) change in the relative percentage of QM reported as Q1, Q2 and Q3, and (b) volume of gas recorded at Q3(30s), has on the calculated DRI value for each coal sample. Comparing the results of samples 3 and 21, both samples having QM = 10.0 $m^3$/t and DRI = 1700; the Q3 of sample 3 is 4.0 $m^3$/t (Q3/QM = 40%) and Q3(30) = 510 mL, and the Q3 of sample 21 is 7.0 $m^3$/t (Q3/QM = 70%) and Q3(30) = 893 mL. This example highlights how two coal samples with significantly different gas emissions characteristics can produce equal DRI values.

Figure 18 compares reported gas test results from six (6) Australian coal mines, each sample having QM = 10 $m^3$/t and DRI = 1200. The results highlight the variability that can occur in the reported gas content component values, IDR30 and Q3(30s), without impacting the DRI value.

Lama and Bodziony (1996) discuss a number of outburst prediction indices that have been used in different countries. Whilst each index may vary in some way, whether it be (a) sample particle size or sample mass, (b) measured volume or pressure of desorbed gas, or (c) duration of measurement period, all methods test fresh coal and focus on initial desorption rate. In the current Australian Standard for gas content testing, AS3980:2016 (SAA, 2016), the only measure of initial gas desorption rate is the IDR30 which is a measure of the volume of gas released from a coal samples in the initial 30 minutes immediately following sample collection, measured in $m^3$/t. The relationship between DRI and IDR30 relative to gas content

(QM) for both CH4 and CO2 rich coal samples has been considered. Gas data from testing CO2 rich coal sourced from reference mines M1 and M15 is presented in Figure 19, and gas data from testing CH4 rich coal from reference mines M8 and M12 is presented in Figure 20. The gas data from the mines presented in both figures shows that while the average relationship between DRI and QM is linear, there is a non-linear and notable increase in IDR30 from samples with higher QM.
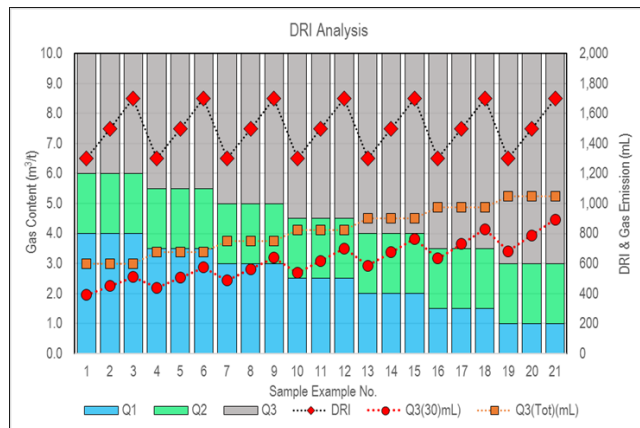


Figure 17: Comparative assessment of Q1, Q2 and Q3 component percentage of QM and Q3(30) on DRI for samples with QM = 10 m³/t.
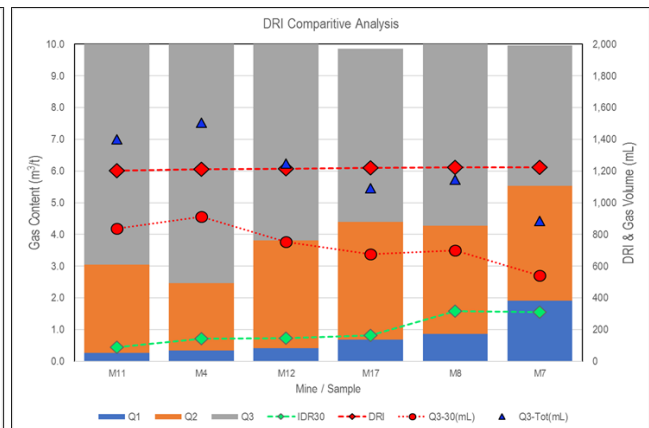


Figure 18: Comparative assessment of Q1, Q2 and Q3, IDR30 and Q3(30) for core samples with QM = 10 m³/t and DRI = 1200.
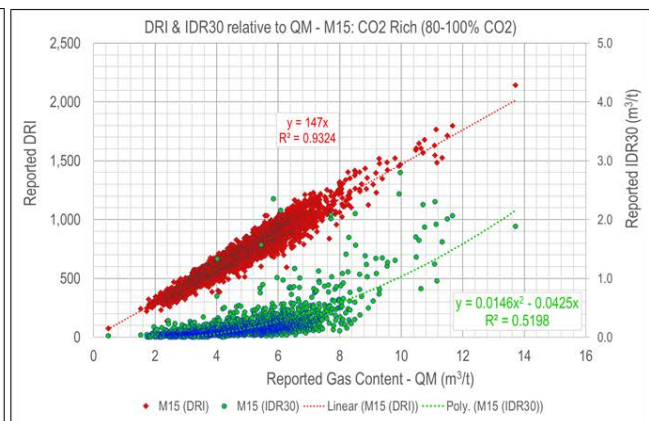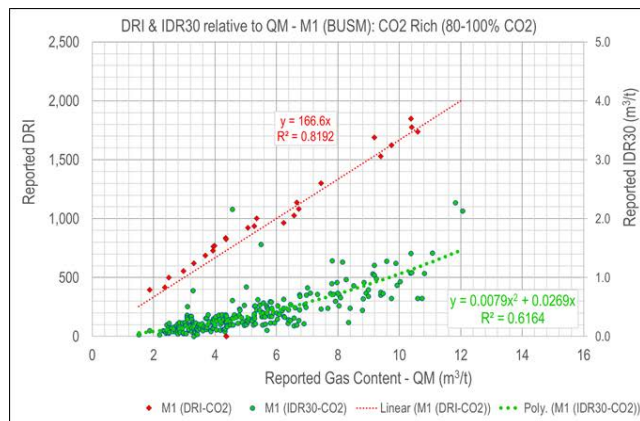




Figure 19 – Percentage of Q3 gas release in first 30 seconds of crushing CH4 and CO2 rich coal relative to sample QM
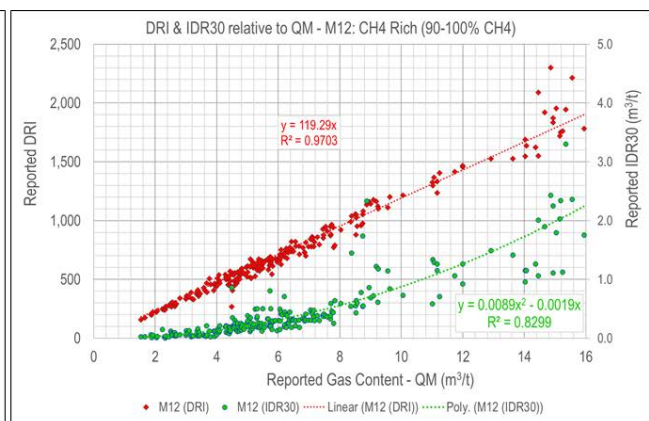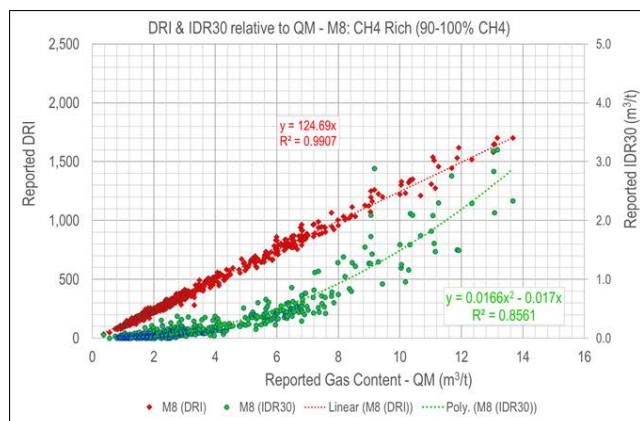




Figure 20 – Percentage of Q3 gas release in first 30 seconds of crushing CH4 and CO2 rich coal relative to sample QM

## OTHER FACTORS THAT IMPACT OUTBURST THRESHOLD LIMITS

Many theories have been presented regarding the type and significance of factors that contribute to the occurrence of coal and gas outbursts (Black *et. al.*, 2009). Lama (1995) listed the following five factors considered to have the potential to contribute to an outburst:

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

Lama (1995) reported that from previous studies, gas was considered the major contributing factor to outburst occurrence in the Bulli seam. Gas content has therefore used as the primary indicator of outburst risk in all Australian underground coal mines and, where gas content is found to be at levels above the threshold limit, gas drainage is used to reduce gas content below the threshold level prior to mining (Black and Aziz, 2008). There are however many other factors that are relevant, and should be considered, in an assessment of outburst risk (Lama and Bodziony, 1996, Black *et al.*, 2009, Gray *et al.*, 2016). The factors considered to have the most significant impact on outburst risk have been presented in the outburst risk matrix shown in Figure 21.
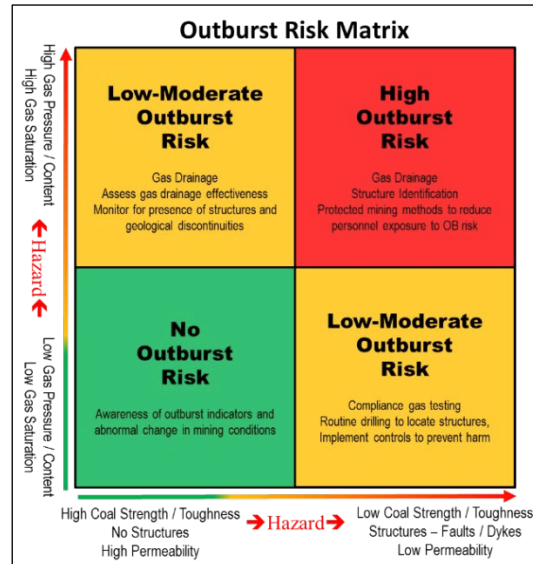


Figure 21 – Outburst risk matrix (after Black *et al.*, 2009)

Black and Aziz (2010) reported several Bulli seam mines that had introduced increased outburst threshold levels and discussed concerns that the Bulli Seam Benchmark and use of DRI900 as the basis for determining outburst threshold limits may not be appropriate.

Recent investigations into Australian outburst history and mining experience in areas where gas content was above the 1994 Bulli seam outburst threshold limits has provided no evidence that outburst had occurred at gas content levels below approximately 9.5 m³/t, independent of gas composition. Most outburst events are associated with abnormal geological conditions. Walsh (1999) reported that of the approximately 250 outbursts that had been recorded at West Cliff colliery at that time, 70% occurred on strike-slip faults, 4% on dykes and faults, 1% on thrusts, 3% on normal faults; and 19% on bedding slips.

Figure 22 provides a summary of core sample gas test results from areas where gas content was above the 'normal mining' outburst threshold limit, that were mined using non-standard mining methods. Subject to the mine and their respective outburst risk management process, non-standard mining methods may include fully remote mining, grunching (shotfiring) and mining at reduced advance rate (limited rate mining). Tahmoor colliery has utilised limited rate mining for more than 15 years without an outburst, through both structured and non-structured coal, with gas content up to 12.0 m³/t (CH4) and 10.0 m³/t (CO2) (Borg, 2014).
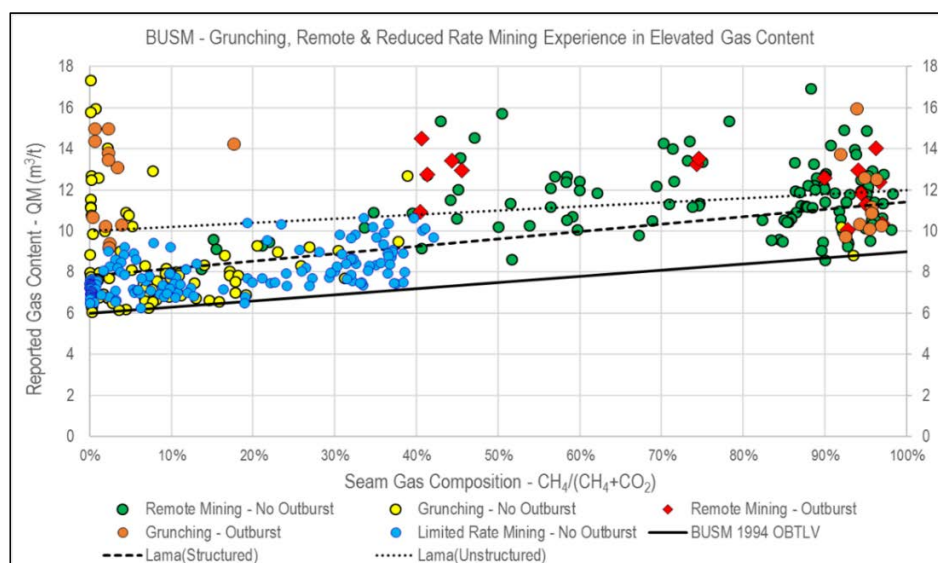


Figure 22 – Summary of grunching, remote and reduced rate mining experience in Bulli seam mines (post 1994)

The experience at Tahmoor colliery demonstrates the ability to successfully manage outburst risk, to enable mining to be carried out, without outburst, in areas where gas content is greater than the 1994 threshold limit for 'normal mining'.

Further work is required to determine safe threshold limits, considering the key factors that impact outburst risk. Research is continuing, in conjunction with the University of Wollongong, to develop an Outburst Risk Index that considers other factors in addition to gas content/pressure, such as coal toughness, that may be used to assess outburst risk in Australian underground mines.

## CONCLUSIONS

Investigations into the characteristics of the Bulli Seam Benchmark, using gas data collected from areas recently mined in the Bulli seam, has identified changes in the average QM-DRI relationship compared to data presented in 1995. Further investigation of the method used to calculate DRI has highlighted that (a) the performance of the crushing equipment, and (b) the crushing and gas emission measurement procedure used to determine Q3, has a significant impact on the DRI value, which also affects the Bulli Seam Benchmark.

Investigations into DRI and the factors that affect the QM-DRI relationship demonstrated that the average QM-DRI relationship for each coal seam varies in accordance with the relative percentage of total gas emission recorded during Q3 testing that is released in the initial 30 second of crushing, i.e. Q3(30s)/Q3(Total). Moreover, the use of DRI incorrectly assumes that the rate of gas release from a combined mass of 150 or 200 grams of mechanically crushed coal, during Q3 residual gas content testing, is a measure of gas desorption rate. DRI is the only measure used to assess outburst risk and define outburst thresholds limits that is based on measurement of the gas emission rate from crushed coal in the later stages of gas content testing.

Gas content is considered to have the most significant impact on outburst risk and gas drainage to reduce gas content to safe levels plays a significant role in control and reduction of outburst risk in Australian underground coal mines. There are other significant factors that affect outburst risk and mining experience has demonstrated that where outburst risk factors, such as abnormal geological conditions are not present, that mining can be conducted without outburst at gas content levels greater than current normal mining threshold limits, and greater than those presently determined using the DRI900 method.

Further work will continue in association with the University of Wollongong to (a) investigate and determine threshold limits appropriate for other outburst risk indicators, such as coal toughness and gas pressure, and (b) develop a multi-factor Outburst Risk Index appropriate for assessing outburst risk in Australian mining conditions.

## ACKNOWLEDGEMENTS

## REFERENCES

Black, D J and Aziz, N I, 2008. Improving UIS gas drainage in underground coal mines, in Proceedings of the 8th Underground Coal Operator's Conference COAL2008, University of Wollongong, (eds: N I Aziz and J A Nemcik), Wollongong, 14-15 February, pp 186-196

Black, D J and Aziz, N I, 2009. Reducing coal mine GHG emissions through effective gas drainage and utilisation, In Proceedings of the 2009 International Coalbed & Shale Gas Symposium, University of Alabama, Tuscaloosa, 18-22 May, Paper No. 0912.

Black, D J and Aziz, N I, 2010. Coal properties and mine operational factors that impact gas drainage, in Proceedings of the 13th U.S. / North American Mine Ventilation Symposium (eds: S Hardcastle and D L McKinnon), Sudbury, Ontario, 13-16 June, pp 251-258.

Black, D J, Aziz, N I, Jurak, M J and Florentin, R M, 2009. Outburst threshold limits – are they appropriate?, in Proceedings of the 9th Underground Coal Operator's Conference COAL2009, University of Wollongong, (eds: N I Aziz and J A Nemcik), Wollongong, 12-13 February, pp 185-192

Black, D J and Aziz, N I, 2010. Outburst threshold limits – current research outcomes, in Proceedings of the 10th Underground Coal Operator's Conference COAL2010, University of Wollongong, (eds: N I Aziz and J A Nemcik), Wollongong, 11-12 February, pp 203-209.

Borg, J, 2014. Grunching Through Potential Outburst Zones – Tahmoor underground colliery, presentation at the ACARP Gas and Outburst Seminar, November 2014.

Gray, I, Shelukhina J and Wood, J, 2016. A practical approach to the determination of outburst threshold, in Proceedings of the 2016 Coal Operator's Conference, University of Wollongong, (eds: N Aziz and B Kininmonth), Wollongong, 10-12 February, pp 330-346

Lama, R.D. (1995) Safe gas content threshold value for safety against outbursts in the mining of the Bulli seam, Int. Symp. cum Workshop on Management and Control of High Gas Emissions and Outbursts in Underground Coal Mines, Lama, R. D. (ed.), Wollongong, Australia, pp. 175–189

Lama, R. D. and Bodziony, J. (1996) Management of outburst in underground coal mines, International Journal of Coal Geology, Vol. 35, pp. 83–115

Standards Association of Australia (2016) Guide to the determination of gas content of coal – direct desorption method. Australian Standards AS3980-2016.

Walsh R, (1999) West Cliff Longwall Outburst – update; Half day Seminar, Gas and Coal Outburst Committee, Wollongong, 23 June 1999.

Williams, R. and Weissman, J. (1995) Gas Emission and Outburst Assessment in Mixed CO2 and CH4 Environments, ACIRL Seminar – Prosperity with Safety in a Hostile Environment, Brisbane, University of New South Wales, pp. 1-13.

Williams, R.J (1997) Definition of outburst threshold limits from core testing [Online] Available: http://www.geogas.com.au/files/u2/OutburstThresholdOct1997.pdf [Accessed December 2008]

Williams, R.J. (2002) Gas content testing for outburst management compliance, 3rd Australasian Coal Operator's Conference, Wollongong 6-8 February 2002, pp. 47-52