ACARP 10012

OUTBURST SCOPING STUDY

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SCOPING STUDY
OUTBURST MANAGEMENT IN AUSTRALIA

1.   EXECUTIVE SUMMARY

1.1 Objective

The objective of this scoping study is to develop, through consultation with operators and researchers, a strategy for upgrading outburst management controls in the Australian Coal Industry, including a research plan to support improved outburst management. In this context "upgrading" relates to improving efficiency and effectiveness of outburst control.

The definition of an outburst for the purposes of this report is as follows:

"An outburst is the failure and sudden ejection of coal and gas, resulting from a release of stored potential energy"

1.2 Scoping Study Process

As part of this study, the following were conducted:

a) A survey of mines currently using gas drainage and/or Outburst Management Plans;
b) A survey of mines, mining technical staff, researchers, consultants and government personnel, regarding their perceptions of the needs for research, development and application;
c) An Outburst Research Needs Workshop, attended by 20 invited operations leaders, regulators and researchers;
d) Discussions with experienced individuals; and,
e) A synthesis of findings into a series of recommendations.

1.3 Current Status of Outburst Knowledge in Australia

Lama and Bodziony, 1996, provided a comprehensive review of international knowledge of outburst theory and outburst management. The only real advance in the understanding of outbursts since then in Australia has been the computer modelling work by Wold and Choi of CSIRO.

Most Australian mines successfully drain gas to below the threshold limits for safe mining. The cost of gas drainage is high with approximately 370,000 m of drainage holes drilled per year at a cost of around $37M. Where drainage is not successful, grunching or other means of mining has to be conducted, adding say, an extra $10M per year. Outburst mangement by the Australian coal industry is expensive, and although it is generally effective it is not very cost efficient.

In recent years, five outbursts have been recorded. Four of these occurred as failures of Outburst Management Plans. There have been two unexpected outbursts recorded on a longwall face at West Cliff, one on a dyke at Appin, one on faulting at Central and one controlled outburst on a remotely mined face at Tower. In over 1,600 m of grunching of coal whose gas content exceeded the structure threshold at Tahmoor, no outbursts were induced. This indicates that the threshold at Tahmoor may be set too low and that many millions of dollars have been spent to avoid outbursts that may not have occurred.

How well do individuals employed in the Australian coal industry, really understand outbursts and their management ? The recognised experts have demonstrated good understanding of the phenomenon, but many others in the industry, including some senior managers and public officials, appear to have a relatively poor understanding of the theory. If outburst management is conducted in an environment of inadequate understanding, how good is it? There is an abundance of gas content data in the field but there is a serious lack of other data relevant to understanding outbursts. Current outburst management is based on only one parameter - gas content. This is poor science.

1.4 Research and Development Required by Industry

Expenditure

Over the last 10 years, ACARP has funded around $6.5M of gas management and outburst-related research. Figure 1 shows annual commitment of funds. The years of greatest expenditure followed the fatalities at South Bulli (1992) and West Cliff (1994). Many of these research projects failed to achieve their objectives, partly because industry did not take ownership and did not provide the projects with field trial support. Furthermore, research has proven challenging when outbursts are actively avoided in mining.

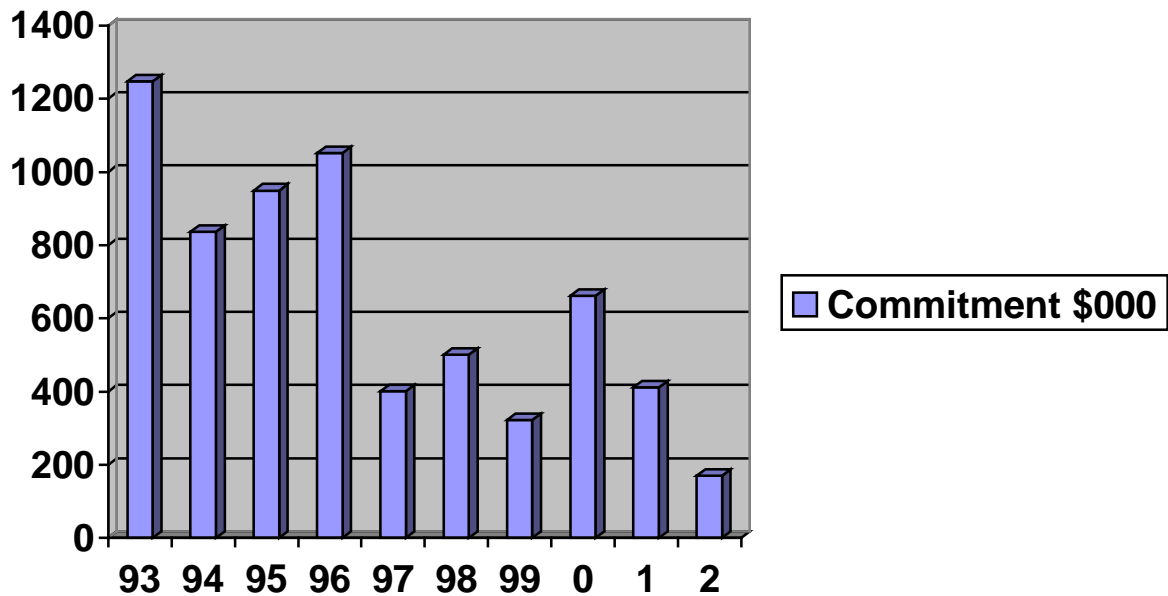**Figure 1 ACARP Commitment to Outburst and Gas Related Research (incl In-seam drilling)**

Industry Needs

What outburst research and development is required by industry?

A survey of industry players was responded to by only 25 individuals. Whilst the response provided a good cross section of industry experience, the quantum was disappointing (apathy or a sense of outburst knowledge inadequacy by those surveyed?).

In addition, an Outburst Research Needs Workshop, conducted in February 2003, was attended by 20 invited participants who provided an effective cross section of those who have to deal with outbursts – operators, regulators, service providers and researchers.

From these two initiatives, the main outburst issues facing the industry were determined as:

a) Current outburst protocols, which seem to work reasonably well in the Bulli seam, might be giving a false sense of security in other geographical locations (eg Qld);
b) Limited fundamental basis for current protocols (based on empirical conservatism);
c) Appropriate barrier sizes (extension of holes beyond roadways);
d) Some relevant O/B parameters not considered in O/B management – eg stress, strength, gas pressure, etc;
e) Better understanding required for all stakeholders of outburst mechanism including roles of parameters such as stress, strength, gas pressure, etc ;
f) Problems draining "tight coal";
g) Problems drilling and draining highly stressed or broken ground;
h) Ambiguity regarding "structured coal" classification with respect to outburst thresholds;
i) Confident location of outburst-prone structures (are some structures actually more outburst prone than others?);
j) Data acquisition inefficient and imprecise;
k) Poor predictive systems;
l) Becoming insular in our approach; and,
m) Training and awareness processes inadequate – learning not sustained

The workshop produced a set of requirements for the next 5 years:
a) Validated and agreed understanding of outburst mechanism;
  - Articulated
  - Relevant parameters and measurements
  - Understand the limits of application
b) Tools to rapidly and efficiently reduce gas content/pressure (routine and last resort);
c) Ability to identify different zones of O/B proneness/management with adequate response time;
d) Better means to negotiate high risk areas;
e) High confidence in defining structured areas and risk areas;
f) Develop methods to easily measure pressure gradients, stresses, strength etc;
g) Understand the discrimination of structure size/nature;
h) Develop permeability enhancement tools;
i) Develop and trial methods to drill and drain in highly stressed or broken ground; and,
j) Routine/reliable use of in-seam geophysics.

There are three primary goals derived from the above research and development requirements:

Outburst Research Goal 1:
  Review and specify the outburst mechanism and the roles of the various parameters. The parameters must be practically measurable. Once the researchers have defined the mechanism, it will have to be communicated to all players.

Outburst Research Goal 2:
Understand the (structural) conditions which cause zones of poor drainability or drillability and therefore, increase outburst proneness, and to confidently locate these zones with adequate response time

Outburst Research Goal 3:
Develop and apply tools (methods) to rapidly, efficiently, and preferably economically reduce gas content/pressure as a routine and as a last resort.

Technical staff at the mines also place a high priority on the need for awareness development, eg continuing gas and outburst seminars, a web site with papers on gas and outbursts and a forum for active discussion and debate and refinement of procedures.

How to Achieve the Goals

Ideas maps are shown in Figs 2,3,and 4. Specific recommendations are listed in section 10 and suggested research projects with approximate costings are tabulated in Table 3. The approximate cost of research will be around $3 million to the industry and around $1 million per supportive colliery.

To obtain relief in the short term from the restrictions of mining to the structure gas content threshold (the permitted maximum gas content when there is no proof that the coal to be mined is free from structures which could promote an outburst), mines can prove the coal to be mined is free from structures. Current drilling applications are not accurate enough to permit this.

To improve the reliability of structure detection, mines can:

a) Use automated drill rig monitoring on each drill rig with data analysis by a competent professional;
b) Use a monitored rotary drill such as the BHP/ACARP developed monitored ProRam;
c) Support commercialisation and trial of the Sigra torque/thrust tool (high priority);
d) Trial the CSIRO dielectric tool (high priority);
e) Trial the Lunagas/AMT drill fluid logging system;
f) Trial the Sigra borehole pressurisation system and cuttings sampler; and,
g) Install piezometers or packers ahead of a mine face to demonstrate that gas pressure gradients are benign; the pressure gradient should be known if development rates are to be optimised.

Most of the above devices were developed to prototype stage with coal industry (ACARP) funding, but they are not intrinsically safe. If they are not supported and given fair trials, they never will become available commercially.

Longer term goals can only be achieved if mines take ownership of the necessary research and development and conduct their own investigations and measurements of gas and outburst parameters. ACARP, researchers and service providers can assist, but active and enthusiastic mine site support and drive are essential, as is mine site innovation.

Any trials or investigations, including the definition of the roles of parameters other than gas content, need to be conducted according to the scientific process, be well documented and subjected to peer review. The knowledge gained should be shared with other industry members. The scientific process comorises basically 5 steps:

1. Observation
2. Initial measurements
3. Analysis and Hypothesis
4. Detailed measurements and data collection
5. Analysis and theory development

Unfortunately it is all too common practice (in mining as well as other fields) to jump from step 1 to 3 and call it 5. Steps 2 and 4 are often by-passed. Thorough documentation is required for sharing knowledge, for historical records and for peer review and challenge.

To understand the outburst mechanism and the roles of parameters other than gas content, mine personnel need to work with researchers to collect basic data on the importance of many factors including coal seam structure, strength, gas pressure, pressure gradients, stress, strain, etc. The data can then be used as input to models such as that developed by CSIRO (Wold & Choi), for assessing the relative roles of each parameter. The model could then be used to back-analyse historical outbursts from, eg Leichhardt, Collinsville, Metropolitan, Appin, West Cliff and Central Collieries. There is also a need to consider the value of an experimental outburst mine. In its last three years, Leichhardt Colliery was such a research mine. The data collected over twenty years ago provided some of the base data for the current CSIRO outburst models.

Other data could be acquired by detailed monitoring of a controlled outburst induced by remote mining. The outburst should be fully monitored, including a video record which could be later used for training purposes. To mine coal that will not drain, there are several techniques which were summarised by Lama and Bodziony (1996). These techniques could be trialed at host mines with full monitoring and documentation.

Section 10 of this document provides some recommendations for achieving industry's goals for outburst research. However, a coordinated approach to data collection and research is required if the goals are to be achieved. A coordinating committee is required, made up of recognised gas and outburst "experts", senior industry representatives and regulators from NSW and Queensland. The chair person should be an unbiassed person experienced with outbursts. A commitment is required from mines to supply existing data, to collect new data and to support ACARP projects and trials.

There is a need to encourage post graduate education of mining engineers and geologists working in the industry to support succession of gas and outburst professionals. Mine support of such continuing education would provide on-site personnel for data collection and assessment. There are many people in the mines who could act as important mentors for younger colleagues. Publication of reports on trials, incidents, etc would assist the Australian coal industry to regain the world-class recognition it had for outburst management in the days of Ripu Lama and Alan Hargraves.

Recommendations made in this study may be challenged on the basis that nobody working in the mines has the time or financial support to conduct much in the way of scientific study,

data collection, data interpretation and analysis, let alone even think of publishing. Cutting coal is the top priority, as it should be. However, the lack of time to think, analyse etc surely is a symptom of one of the prime problems facing outburst management and other technical aspects of mining. If personnel lack the time, encouragement or resources to fully analyse problems, including collecting appropriate data, they will act on instinct or gut feeling and this can be fatal in respect to outbursts. If nobody in the industry has the time to advance outburst and gas research, as defined in the goals previously mentioned, and industry hopes the researchers or ACARP can do the job by themselves, then the industry is unlikely to successfully deal with outbursts in the future.

Comments by Alan Fisher at the Coal and Gas Outburst Seminar Committee's June, 2003 Outburst Seminar are timely:

> *"My concern is that nobody in mines can, with absolute certainty, 'guarantee' that it is safe to mine in every set of outburst prone conditions or indeed that they, at that time, have sufficient information to make this decision. This is even more true when structure may be involved."*

> *"If men have been killed in an outburst, you are certain to be subject to a searching enquiry and then probably prosecuted. You will not be able to rely on having complied with some of Ripu's or anyone else's books or recommendations except for mitigation."*

> *"I cannot see how any company can say with certainty that they at all times have the people in place who are competent to make the right decisions every time."*

> *"Companies'/mines' failure to find themselves able to support trials of development/refinement of equipment or techniques, for example to better define structures, could well be held against those companies and/or their officers in such prosecution proceedings."*

> *"To summarise, mines with difficult outburst decisions are probably good places to stay away from. At such places one just cannot declare with absolute certainty you will be right every time. There is still some room for gut feelings and a need for lateral thinking, but this must be backed up by actions to improve safety margins and most importantly, documentation of the decision process. Particular documentation should be kept of all those times when mining was not allowed to proceed."*

John Hanes
BSc (Geology), FausIMM
August, 2003

Managing Outburst-prone Coal or Poor Drainage Coal or Difficult Drilling

Outburst Mitigation

- **Unstable Ground**
  - Scroll drilling
  - Waterjet drilling
  - Recovery of bogged equipment
  - Drilling parallel to horiz.stress
- **Other Mining Methods**
  - Shotfiring
  - Pulsed infusion
  - Remote Mining
  - Auger mining
  - Advancing longwall
  - Arched roadways
  - Sacrifice roadways
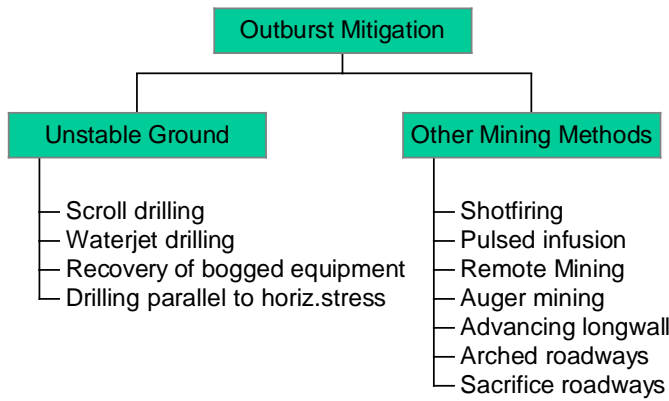
Figure 2 Outburst Mitigation Options

Outburst Awareness and Coordination

Outburst Coordination

Industry steering committee

- **Seminars**
  - State of industry progress
  - Case studies
  - Issues discussion
- **Website**
  - Web forum
  - Publications
  - Contacts
- **Research**
  - Research Organisations
  - Minesite R&D
    - Mine personnel
    - Postgrads
- **Regulators**
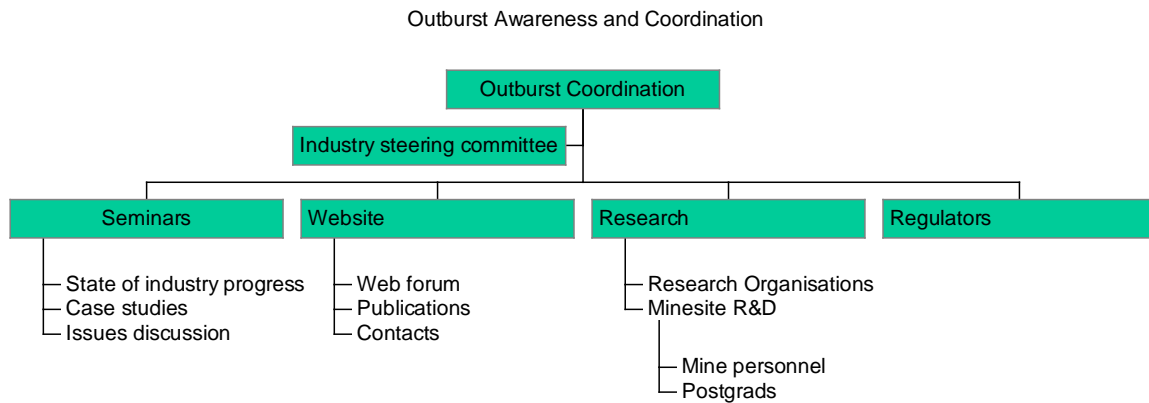
Figure 3 Outburst Awareness & Training Options

Reliable Outburst Model

Outburst Mitigation

- **Gas Parameters**
  - Content
  - Composition (change)
  - Pressure (gradients)
  - Desorption behavior
  - Diffusion
  - Energy state
- **Permeability**
  - Field perm
  - Lab perm
  - Directional perm
  - Perm change
- **Stress**
  - Palaeo
  - Insitu
    - Coal (tool ??)
    - Stone (overcore)
- **Structure**
  - Regional
  - Local
  - Monitoring
    - DHM rigs
    - ProRams
      - Torque/thrust
      - survey
      - stabiliser
- **Strength**
  - Lab
    - confined
    - unconfined
    - shear
  - Field
    - gouger
    - point load
    - miner head power
    - torque/thrust

Figure 4 Reliable Outburst Model Issues

2. INTRODUCTION

2.1 Background and Concerns

Concerned with the lack of debate on outburst gas controls, the author, on behalf of a group of gas specialists, submitted to ACARP in 2001 for funding of a series of specialist meetings to review the outburst management situation and to advise on future research. The submission was not initially successful, but the author was subsequently contracted to develop a strategy for upgrading outburst management controls in the Australian Coal Industry. The previously mentioned gas specialists contributed to this study by their participation in and contribution to an Outburst Research Needs Workshop held in February, 2003 and by providing critiques of this report.

Bulli seam mines are mining under a "Section 63" notice, which prohibits mining coal which contains gas at contents greater than imposed threshold values. To reduce gas contents to lower than the threshold levels requires extensive and expensive gas drainage drilling. Queensland collieries have effectively adopted similar thresholds to the Bulli seam, but modified accord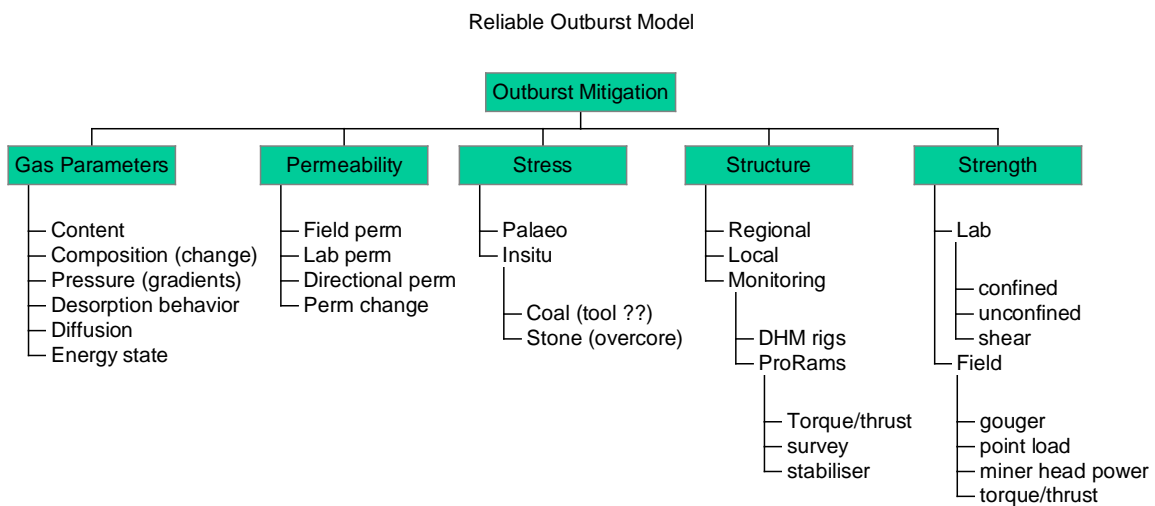ing to advice by Geogas Pty Ltd, based on Q3 desorption rates. The gas content thresholds were introduced into the Illawarra coal mines by Dr Ripu Lama (Lama, 1991) and subsequently reduced in level by the Section 63 notice. The threshold levels have not been changed since the Section 63 notice was introduced and a review of them is well overdue. Mining coal containing gas at contents less than the thresholds has successfully prevented outbursts.

There are only a few outburst and gas specialists remaining in the Australian coal industry. They generally work independently and are aging. The same can be said for outburst-experienced mining personnel. There is a need for the industry to keep good researchers working in the industry on industry problems. In the early 1980's, there were many researchers working on gas problems. With changes in the industry, interest progressively lapsed and most of these researchers left the industry. This trend should be reversed. There are too few quality researchers available and it is necessary to have these people working together for the benefit of the industry.

During his visit to Australian mines in 1999, at the invitation of the Coal and Gas Outburst Seminar Committee, Professor Antoni Kidybinski stated that he had two main concerns about outburst management in Australia (Kidybinski, 1999). These were that the controls on safe mining were based on one index (gas content) only and there was no expert body reviewing Outburst Management Plans and advising the industry on outburst matters.

2.2 Scoping Study Process

As part of this study, the following have been conducted:
- A survey of mines currently using gas drainage and/or Outburst Management Plans;
- A survey of mines, mining technical staff, researchers, consultants and government personnel regarding their perceptions of the needs for research, development and application;
- An Outburst Research Needs Workshop;
- Discussions with experienced individuals; and,

- A synthesis of findings into a series of recommendations.

Much of the content of this report is the author's bias, according to his knowledge based on 30 years of personal experience with outbursts and outburst research and the advice of many others. Where practicable, the work and ideas of others are referenced. It is taken as understood that the reader is aware of the abundant amount of information and case studies available in the literature including many papers by Hargraves, the proceedings of the 1995 Coal and Gas Outburst Symposium, Lama and Bodziony, 1996 and the half yearly Coal and Gas and Outburst Seminar Committee seminars and the various ACARP workshops and seminars organized by the author in NSW and Queensland over the last 9 years.

3.   CURRENT STATUS OF OUTBURST MANAGEMENT IN AUSTRALIA

3.1 Background

Prior to 1994, outbursts in Australia were not effectively managed. As a consequence of the fatal outburst at West Cliff Colliery in 1994, the then NSW Chief inspector of Mines applied a Section 63 notice to the NSW Coal Industry, setting outburst threshold gas content limits for mining in the Bulli seam. Queensland mines have more or less adopted the NSW recommendations as modified by the GeoGas DRI 900 (Williams and Weissmann, 1995, Williams, 1999). The thresholds were based on recommendations made by the late Dr Ripu Lama of Kembla Coal and Coke. Lama reviewed gas content data for world wide occurrences of outbursts and allowed conservative safety factors when setting thresholds for structured and solid coal. The Section 63 notice declared that the occurrence of outbursts was not acceptable except under remote mining conditions and the threshold gas contents were based on the worst case scenario, ie structured coal.

Mining has been subsequently conducted in the Bulli seam only after the gas contents have been drained below the thresholds. This has been expensive. In Tower Colliery, remote mining was conducted to traverse zones of lower permeability coal which could not be drained below the thresholds in an acceptable time frame. Tahmoor resorted to grunching over 1,500 m of development during which no outburst was induced. The coal was very strong. Could this coal have been safely mined conventionally? Other mines have been similarly affected.

In 1999, the Gas and Coal Outburst Seminar Committee and the industry sponsored a visit by Professor Antoni Kidybinski of Poland to review Australian mines' outburst management practices. Professor Kidybinski commented that he saw two main problems with outburst management in Australia.
- Only one indicator, gas content, is being used as a threshold; and,
- There is no overriding expert group to determine the effectiveness of Outburst Management Plans and for guidance of the industry.

The current gas content thresholds have been successful in preventing outbursts on conventional development faces, but will they prevent outbursts when mining conditions change from the present conditions? Are they appropriate for the proposed deeper mining in the Illawarra around Campbelltown and Camden. Are they appropriate for all mining in the German Creek or Rangal Coal Measures of Queensland? The current feeling is that other

factors including coal strength, gas pressure, gas type, conductivity, water saturation, cleat mineralisation, permeability, and desorption rate, etc, play roles which must be more closely defined in order to better understand outbursts. The costs of draining gas to the threshold levels, and of remote mining where thresholds cannot be achieved, are prohibitive. Can the industry afford to continue to absorb such high costs for what could be overkill?

There are many relevant data now available at the mines and there is an accumulation of knowledge held by relatively few gas and outburst specialists servicing the Australian coal industry. The specialists are all around over 50 years of age. In recent years the industry has lost access to Dr Ripu Lama (deceased) and Dr Alan Hargraves (stroke), the two leaders in outburst and gas research from the 1960's to 1990's. There is a need to encourage development of a succession of specialists. The current specialists generally work independently of each other but occasionally co-operate on a project or meet at seminars, etc. There is a need to ensure that these individuals meet regularly as a group to exchange ideas, to guide research into gas and outbursts and to advise on safe mining with respect to gas and outbursts. Such meetings would ensure that their knowledge is subjected to peer review and documented for the development of the science and for the benefit of the Coal Industry. There is also a need to make as much company information on gas and outbursts as possible available for industry knowledge and interpretation.

3.2 State of the Art

Knowledge of outburst mechanisms in Australia has progressed in fits and starts and has been well documented (eg Proceedings Int Symp cum Workshop on Management and Control of High Gas Emissions and Outbursts in Underground Coal Mines, (Ed: R D Lama).

A snapshot of the gassy mines in Australia (Table 1) indicates that, in general, there are virtually no current problems with outbursts. They are generally not occurring because most mines manage the prevention of outbursts through efficient drainage of the gas to contents below the structured coal thresholds. Outburst risk is well controlled by adhering to Outburst Management Plans. However, such a snapshot is somewhat misleading. Exceptions exist and are costly.

The main Illawarra exceptions are Tahmoor Colliery which is spending millions of dollars on grunching where gas drainage is not effective within an acceptable time frame and Tower colliery which ceased mining partly because of an impermeable zone which could be neither drilled nor drained. In Queensland, most of the currently operating mines are still in the juvenile stages of gas management, the main exception being Central Colliery which is at greater depth.

Essentially gas and outburst management at each mine is based on gas drainage. In-seam holes, 96 mm diameter, are drilled mainly from one set of development headings, across the proposed longwall block to 10 to 50 m beyond the next proposed development panel. The holes are typically drilled in fan patterns to minimize rig moves. Hole spacings at target depth vary according to seam permeability. In some Queensland coal seams, final hole spacings exceed 50 m whereas in the Illawarra mines, target spacings are 20 m and in relatively impermeable coal such as parts of Tahmoor, the spacing is reduced to 6 to 8 m, or even less. Holes are drilled using a downhole motor and surveyed using an AMT Mecca system or similar. Most drilling is conducted using a 1.25 degree bent sub and 6 m flip-flops. Appin Colliery and one contractor use rotational slide drilling. Accuracy of drilling, within the

limits of equipment used is now accepted and demonstrated. To test the effectiveness of drainage, Illawarra mines typically stop some holes in a fan pattern short of target and only extend them after sufficient drainage time has passed. At this stage the holes are extended to the target zone and cored for gas content testing. Flank holes are drilled when necessary to take cores in the worst possible situation (highest potential gas content) to check drainage efficiency and to check for any structures that might be missed by the fan pattern. In most Queensland collieries, the effectiveness of drainage is tested by the drilling of vertical holes from the surface with coring of the coal seam. Outburst risk is overseen at each mine by a special committee which operates according to the mine's Outburst Management Plan.

Surface to in-seam drilling and drainage is becoming popular in Queensland and in the CBM industry for predrainage.

3.3 Controls in the Bulli seam - Background

The Bulli seam mines of the Illawarra, NSW, work under strict gas content thresholds, enforced by the Section 63 notice (of the Coal Mines regulations) issued by the mining inspectorate. The thresholds are based on recommendations by the late Dr Ripu Lama. The background to Lama's recommended thresholds is summarized in exerts from his papers in Appendix 1 of this study.

According to McKensey, 2001,

> *"after the South Bulli fatalities, the industry tried to prevent harm to the workers. They decided that the best way to do this was to reliably predict structures ahead of the face. The reliability of predicting structures at the time was pathetic. 50% of structures on which outbursts occurred were not predicted in advance of mining... What are the chances of improving the reliability of predicting structures? The industry could not agree on what type of structure could induce an outburst. It was decided that relying on the prediction of structures was very unreliable."*

> *"What measurable parameter will give a reliable indicator? How frequently are samples required?"*

> *"Gas content seemed to fit the bill and was chosen for two main reasons:*
> 1. *Gas content could be reliably measured and the measurements were repeatable.*
> 2. *There is a reasonable chance that a sample would be representative of a larger area."*

> *"Gas content is a reasonable representation of the energy source. As the ability to predict structures was so unreliable, it was decided to accept Ripu's lower threshold values."*

> *"The inspectors in the Southern Group decided they had to enforce parameters. They tried having discussions with industry, but there were too many issues and disagreements. Consideration was given to what gas content levels appeared safe, ie had no outbursts. I wanted to halve the gas content levels as I considered the mines could not manage their outburst systems. The inspectors complained that would lead to closures, so Ripu's lower levels were accepted as the thresholds."*

"It was soon demonstrated by the West Cliff fatality that hole accuracy was pathetic. Since then drilling accuracy has improved admirably."

"There is a need to better understand the energy source and the mechanics of the restraining mass. It is possible there is a finer index of outburst risk than gas content, but there will be pit parameters that cannot be predicted. There must be a reliably measured index. Do not choose another index simply for convenience. Nature is very variable and unpredictable."

"Industry should not rely on what has happened in the past to predict what will happen in the future. The West Cliff fatal outburst was associated with an unpredicted geological structural configuration and these situations can occur in the future. At Tahmoor and Tower, there are situations where the gas cannot be drained and the coal cannot be drilled."

"Outburst mechanisms must be better understood. We must find parameters which can be reliably measured and which are representative."

It can be strongly argued that the above unpopular (at the time) actions by the NSW Inspectorate dramatically reduced the outburst hazard and consequently saved lives. Harvey (2002) showed that in the 4 years prior to the Section 63 notice, there were between 6 and 16 outbursts recorded per year in Bulli seam mines, but in the 7 years following, there was a total of 9 outbursts and no injuries.

The mines of the Illawarra area set their own outburst threshold gas contents based on the section 63 notices which were based on publications of Lama (Appendix 1). Draining gas to below the threshold values has, except for a few minor cases, prevented outbursts. But at what cost? Tahmoor Colliery mines the Bulli seam in a predominantly CO_2 environment. According to Peter Wynne, 2003,

"Tahmoor does more drilling than any other mine in the country. Drilling is typically at 20 m spacing, but where there is a problem, the spacing is halved or in some places is reduced to 6 to 8 m. In some areas, this is not close enough. Normal drainage time is 3 to 6 months, but in the tight areas the time has been extended to up to 12 months and they still won't drain. The only resort is to grunch. We started grunching in late 1999 and since then, have grunched 2600 m of roads through "tight" coal which equates to approximately 1300 rounds of shots. Although all the grunching was done in coal with well above the threshold gas contents, not one outburst has been initiated. In hindsight, we believe all that coal could have been safely mined normally and saved $10's millions. There will be another 3 month longwall delay this year. We only achieve 2 m per shift when grunching."

"The tight coal requires extra drainage time (up to 12 months) and reduced spacings (6 to 8 m) which sometimes helps, but in other cases does not. An obvious feature of the coal on mining is that it is homogenous and very strong. It is not typical Bulli seam coal. It appears more like concrete. Work by Lila Gurba has shown that the reason the coal will not drain is that the microfractures in the coal are filled with carbonate cement. Although we know why it will not drain, we still cannot do anything about it."

"We have trialled a few different techniques to improve drainage. We tried slotting, from the bores with high pressure water. We achieved some impressive looking slots but they did not stimulate extra drainage. Last year we tried hydrofraccing. After initial problems with the gear, we were able to produce fracs, but did not stimulate extra flow."

3.4 Controls in the Bowen Basin

Queensland mines use gas content thresholds determined by GeoGas' DRI test. According to Ray Williams, 1999

"For similar gas contents and compositions, different rates of gas desorption between mining areas are evident, probably reflecting differences in the level of microfracturing, coal type and rank. On the basis of gas desorption rate, Bowen Basin coals are on the whole, more outburst prone than Sydney Basin coals. Whereas gas content threshold levels for high CH4 coals in the South Coast are around 9.5 m3/t, in some parts of the Bowen Basin, threshold levels have been set at 7 m3/t, based on the DRI."

3.5 Survey of operating mines – outburst controls

Table 1 summarises the responses to a mine outburst management survey circulated to Managers of all gassy mines in late 2002. Most mines responded. Five mines in NSW and five in Queensland reported they actively drain gas. Outburst Management Plans are used in each gassy mine with the potential for outburst. In-seam drilling and drainage is the main tool reported for gas drainage and outburst prevention. Around 370,000 metres of in-seam drilling is conducted per year for this purpose - 244,000 m in NSW and 126,000 m in Queensland. The total metreage is increasing. Surface to in-seam drilling was reported for one NSW colliery and three in Queensland.

3.6 Examples of Success and Failure

The success of the current Outburst Management Plans and the application of the gas content thresholds is evident by the non-occurrence of outbursts. However, there have been a few recent examples where the Outburst Management Plans have failed to prevent outbursts. These examples are documented below.

3.6.1 West Cliff Longwall Outburst

by Richard Walsh, Acting Planning Manager
(Gas and Coal Gas and Outburst Seminar Committee seminar, 23/6/99)

"Two outbursts occurred from the face of longwall 23 on 3/4/98. Depth of cover for West Cliff is 470m to 500m, the Bulli seam is 2.5m thick. Most of the mine has CH4 up to 15 m3/tonne, but in the north, where the outbursts occurred, the gas is 100% CO2 to 22 m3/tonne. Approximately 250 outbursts have occurred on development since 1976."

"At West Cliff, on a longwall shear run, the drum is set high in the seam and coal mainly drops off the face. On a flit run, the shearer is low to clean up. The outbursts were discovered by the shearer driver during a flit run. He noted excessive coal had fallen. There was a half hour window of opportunity in which the bursts could have occurred. The cavities were at 45 and 54 chocks. The cones extended +1m at the top of the seam. There was no evidence of

coal carried into the chocks. Richard calculated that 16 to 17 tonnes of coal was ejected from each burst that remained on the face (additional coal was run off the face by the AFC)."

"There was no real-time monitoring of CO_2 in the area. The deputy only had 7% CO_2 tubes available which went off scale. +7% was recorded inbye outburst number 1 a half hour after the first reading. At 2 hours the reading was 0.8% with levels increasing from intake to inbye side of the bursts, ie gas was still being liberated from the cavities and could be heard as an audible hiss and a visible haze. The outbursts occurred at the limit of gas drainage. A decision had been made by the previous owners to finish LW22 then move to North Cliff. Therefore the initial 350m of 487 Panel was prepared on drill/drain/drive pattern of drilling. In 487 Panel, holes were drilled at a nominal 2m spacing for 20 m3/tonne CO_2 and a low permeability of 0.25 mD. Thresholds were not a factor of drainage. The patterns aimed to reduce gas to 7 m3/tonne over the 3 months time available between drilling and extraction. The outbursts occurred at the limit of the gas drainage."

"The virgin gas content at the bursts was probably around 20 m3/tonne, cores confirmed this even 2 weeks after the bursts. Gas was available to drive the bursts. No abnormal structures, strike slip or thrust faults were noted. A bedding parallel slip (BPS) is present in the seam, about 100mm below the roof. There was less than 1mm of gouge on the BPS. There was no prominent cleat at the site. There were some inclined cleats across the face but not at the bursts."

"At West Cliff
- *70% of outbursts have occurred on strike slip faults;*
- *4% on dykes and faults;*
- *1% on thrusts;*
- *3% on normal faults; and,*
- *19% on bedding slips."*

"A RIM survey was conducted after the outbursts, but nothing was detected other than gas and water migration. The burst coal was blocky. In the lower part of the seam, the coal had hardly moved other than some rotation."

"A risk assessment was conducted and the face straightened. The Outburst Management Plan now includes longwall face outbursts. Gas contents are to be measured on the longwall face if borehole spacing is less than for development roadways."

3.6.2 *Appin Dyke Outburst, 18/3/2002*

by Richard Walsh, Senior Mining Geologist, BHP Billiton Illawarra
(Gas and Coal Gas and Outburst Seminar Committee Seminar, 26/6/02)

"Appin colliery mines the Bulli seam which is between 2.5 metres and 3.5 metres thick at depths between 480 metres and 520 metres. The virgin gas content is between 12 and 14 m3/t. The seam gas pressure is approximately 4 to 5 MPa. The seam gas is 95% methane."

"Fan pattern holes were drilled across the block to drain the coal on either side of a projected dyke. A potential poor drainage area was recognised. Eleven additional fan holes were drilled and drainage continued for more than 300 days. The holes were probed to ensure no gas accumulation. Gas content samples yielded 3 to 4 m3/t from either side of the

structure (but closer to the left hand heading which was driven first. On the virgin side sampling was conducted in the worst possible situation."

"Despite an extensive gas drainage pattern, a small area of gas had not been drained from around the right hand or virgin heading intersection of the complex structural geology and on mining, a small outburst occurred. The gas drainage drilling had adequately defined the dyke, however the existence of a 2 metre wide strike slip shear zone on the outbye side of the dyke was not identified. The outburst warning signs prior to the outburst were expected due to the approaching dyke and so did not effectively alarm the operators."

"30% methane and 9 ppm carbon monoxide were noted on the mentor. There was a pungent smell which was thought to be from the CO as a result of cross contamination from higher order hydrocarbons. 90 m3 CH4 was liberated from the outburst and 200 m3 was liberated over 90 minutes."

"The Outburst Management Plan was reviewed and density of gas content sampling around expected structures was increased such that even if a structurally complex feature fails to be fully drained then the volume of gas will be insufficient to initiate a significant outburst."

"Questions:
Phil Mitchell – Do you take gas content measurements during initial drilling and on either side of structures? Was any other structure (other than the dyke) identified in the right hand heading?
Richard – Appin take samples from the ends of the fan holes from virgin conditions. After drainage, some holes are extended and cores taken to assess drainage. In this case, no cores were taken to assess drainage around the dyke prior to mining. In the RH road, the strike slip fault was 0.5 m from the dyke, ie within the cinder zone.
Alan Fisher – Were was the 30% CH4 reading taken?
Richard – It was a general body reading from a Mentor in the work area at the face.
Alan – Was there any CO2?
Richard – There is around 3% to 4% CO2 in the coal. Nobody suffered any problems from CO2, but I need to check the CO2 monitors.
Les Gardner – What was the continuous miner doing when the outburst occurred?
Richard – It was cutting. They heard two bumps, observed the increased gas make and then noted the cavity and realized there had been an outburst. The dust was not an issue. The men moved back off the miner and noted the increased gas levels. The monitor on the miner tripped on overload, so there are no monitor results.
Bill Barraclough - The head was at the floor when the miner tripped. There had been previous trips when the head was in floor coal.
David McLean, Dartbrook – Do you take gas samples prior to drainage and prior to mining.
Richard – The holes are active drainage holes which are extended and cored for gas testing.
David – Do you have concerns over end of hole effects?
Richard – We take cores in the suspected worst case conditions. Ripu Lama determined end of hole conditions for West Cliff. At Appin we have to drain out the envelope before drainage extends beyond the pattern."

3.6.3 Tower Outburst with Remote Control Mining

by David Benson, Project Engr, West Cliff Colliery, prev Tower Colliery

The following presentation was taken from a training video prepared by David Benson for BHP. The video showed the control station set-up and the outburst cavity. The outburst was not recorded on a video recorder.

"On Saturday 9th December, 2000, an outburst occurred at 4 am during remote controlled mining at Tower Colliery. The mining was conducted strictly following the Outburst Management Plan and procedures. The outburst occurred while mining through a dyke which had been encountered during previous mining."

"Although the dykes encountered in earlier developments were harder and thicker, the dykes in the tailgate of LW18 were 0.4 m thick and composed of soft clay. The dyke zones were drilled and drained and then mined with no problems. In the development of the main gate of LW18, the two dykes were accompanied by a thrust fault. Gas drainage holes were drilled parallel to the roadways towards the dykes, but bogged in the zone giving a good indication of the zone. Cross panel holes were attempted to drain the zone, but the drills bogged on intersecting the zone and drilling equipment was lost."

"Mining operations in the LW18 maingate stalled for 3 to 4 months. Extensive drilling was conducted using conventional and scroll drilling in an attempt to drain the gas to below the threshold. In spite of the amount of work, the gas content could not be reduced to below the threshold value. An alternative was required. An extensive risk analysis was conducted involving a cross section of the workforce. The Outburst Management Plan had to be altered to allow mining of the zone. Remote controlled mining was used and the belt road was mined without incident, even though the gas content around the dykes was up to 13 m3/tonne."

"Gas drainage holes were drilled from main gate 18 to main gate 19 from the inbye side of the dykes and long holes parallel to the roadways were drilled towards the outbye side of the dykes. The parallel holes reached the dyke zone, but could not penetrate it. Prior to mining, the gas content on the outbye side of the dykes was 5 m3/tonne and on the inbye side of the dyke, 13.5 m3/tonne."

"Remote mining was commenced in main gate 19 in B heading inbye 5 line. A remote operations station was established in the crib room, 250 m outbye the face. The miner driver operated the machine from a consol in the remote operations station. There was real time monitoring by computer screens and a video screen to see what was happening at the face. Two cameras showed the cutting head and the conveyer of the miner. The operations station had phone and DAX system links with control and the face plus an emergency power cut-of for the face equipment. The fresh air base contained Caber gear, which was used by the bolting crew."

"Two face trips occurred during mining through the zone. The outburst occurred when the miner was 9 m inbye the first dyke and was noted during the face inspection following the second trip. Face operations were stopped and the outburst was investigated by a specialist team. The outburst occurred from the top right hand corner of the face. 7.5 tonnes of coal were ejected, but no coal was ejected back over the canopy or to the left side of the miner."

"The outburst occurred on two shear zones. The major zone was located on the right hand side at the platform level of the miner. The gas content prior to mining as determined from a

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coal core was 13 m3/tonne. 1.2% CH4 was measured at the ROZ station. An estimated 70,000 litres of gas were released. The gas was 92% CH4, 8% CO2. The outburst zone had a combination of geological structure and high gas content."

"The outburst mining system worked as designed without deficiencies. The experience reinforced the gas content threshold."

> "Questions:
> **Cyril Piper** – How was coal transported from the face?
> **David** – The coal was cut remotely and dumped onto the shuttle car conveyor. After a 10 minute wait, a minimum number of 3 men could go to the face, operate the shuttle car conveyor and drive the shuttle car out. The crew was 7 men including the deputy.
> **Bruce McKensey** – Was the shuttle car remotely operated?
> **David** – No. It was brought out after the waiting period. This was a slow and not very productive process. In main gate 18 the advance rate through the zone was 2.4 m/shift and in main gate 19 was 2 m/shift. The shuttle car conveyor could not be remotely operated.
> **Chris Harvey** – How was the mining plan developed?
> **David** – Darryl Eason developed the process and described it, the risk assessment and consultation processes at the November 2000 Outburst Seminar. There were some concerns about putting people into a potential outburst environment.
> **Alan Fisher** – Regarding the lessons to be learned, you said that the experience reinforced the thresholds. Did you mean that the experience reinforced that 10 m3/tonne is the correct level, ie safe? It appears that mining might be safe at 13 in some conditions but not in others.
> **David** – At 13.5 m3/tonne with the presence of an appropriate structure, an outburst can occur. In LW18, we mined 240 m through similar structures at 9 m3/tonne and did not get an outburst. The transition appears to be somewhere between 9 and 13.5 m3/tonne.
> **Alan Fisher** – Was the gas content at the face at the time of the outburst actually 13.5?
> **David** – The core, which yielded 13.5, was taken prior to mining, but there was no significant drainage. The coal was difficult to drain. Advance was 2 m per shift. To reduce the gas content to 7 required 90 days of drainage.
> **Konrad Moelle** – Were the dykes weathered?
> **David** – The dykes which occur between Appin and Tower vary considerably. In Appin, the dyke is 10 m wide and 300 MPa strength. Their first intersection in Tower required shotfiring to pass, but in LW 19 the dykes are soft clay 0.4 m thick."

3.6.4 Central Colliery Outburst 20/7/01

> by Dieter Bruggeman, Site Geotechnical Engineer, Anglocoal.
> (ACARP Outburst and Gas Drainage Workshop, Mackay 10/5/02)

"Central mines the German Creek seam which varies between 2.4 m and 2.6 m thick. The seam dips 5 to 6 degrees to the east. Coal strength is 8 MPa. Roof strength varies between 35 MPa and 80 MPa. Normal and strike slip faults occur as well as dykes. Local areas of closely spaced joints occur. Cleats vary in spacing and orientation. Maximum principal stress is horizontal 25 MPa. Mining commenced in 1986 with 200 m wide walls up to 2.8 km long. The deepest workings are at 425 m. The workings have been developed as shown in the plan. There is an extensive gas drainage system in place."

"The outburst occurred at 3:10 am on 20/7/01 in B heading (virgin side of panel) inbye the proposed 28 cutthrough during the bolting cycle (about 1minute after cutting ceased). The miner sumped under and at that stage the drill rigs were at the edge of mesh, with mesh about 0.5 m from the face. They then moved back and lifted the miner head to trim the top of the roof. That is when they heard the first loud bang, causing the miner driver to flit back in high tram, go about 2 metres, then heard the second bang and soon afterwards the face blew. Therefore the time was no more that a minute or so. Around 80 tonnes of coal were affected and 1560 m3 CH4 were released over 2 hours, 50% in the first 20 minutes. A few bruises were the only injuries sustained. The crew were immediately withdrawn to a place of safety while inspections commenced."

"In C heading, the crew reported there was some bumping prior to the burst. One crew member reported that as he was bolting the first mesh, he felt the floor creak. Only one other crew member felt it. It creaked again and they all ran outbye. As they were running, they all felt a big vibration. It sounded like something was stuck in the fan. They then went back to restart bolting. The men were aware of gas and associated problems but none considered that an outburst might have occurred."

"The outburst occurred from an oblique strike-slip fault (see detailed plan). As the gas was released, the free gas in the bedding partings in the roof pushed the roof down a bit. Around 30 cm of roof fell. The coal which was later loaded out was pulverized and typical outburst coal. Major cleats occurred parallel to the fault and were present from the previous cutthrough. They extended from roof to floor and were 25 to 30 m long. They were highly polished. The spacing reduced to 3 m closer to the fault. Roof joints increased in frequency close to the fault and they paralleled the fault. Within 3 m of the fault the coal was shattered."

"The mine should achieve 470 m to 500 m depth eventually. The virgin gas content is 12 to 15 m3/tonne, but is drained down to 2 to 5m3/tonne. The gas is predominantly CH4. Permeability of normal coal is estimated to be 3 to 10 mD. In-seam across block drainage holes are spaced at 50 m. Boreholes flanked the outburst zone at a spacing of 44 m (see detailed plan showing holes, gas contents around face). The gas content threshold is 8.0 m3/tonne based on a DRI of 900 (GeoGas) prior to the outburst."

"Around the outburst, a gas content of 11.68 was achieved about 10 m from the burst after clean up (see detailed plan).
We have learned and adopted the following:
* *The variations in geology should have been evident prior to the outburst;*
* *Gas measurements indicate there was a high gas content gradient away from the in-seam drainage holes;*
* *Outburst Management Plan reviewed based on "Fault Tree Analysis" identified key areas for improvement;*
* *Outside expertise was sought in the investigation process;*
* *Flank hole drilling has now been adopted to overcome the potential to miss structures sub-parallel to the across block holes and for core sampling;*
* *The threshold has been reduced to 7.5 based on 900 DRI;.*
* *A 15 m (10 m) barrier will be left between gas content test samples in areas unaffected (affected) by outburst prone geological structures;*
* *Updated outburst awareness training will be given to all personnel on site; and,*

- *The awareness of in-seam drilling personnel will be increased to the significance of variable drilling conditions."*

"Questions and Comments:
Sean Ewart, North Goonyella – I heard there was a loud thump heard from the roof.
Dieter – There were three thumps heard. They were dull noises like stress relief in the roof.
Ian Gray – If it were not for gas drainage at Central, there would have been outbursts before this one. The gas drainage has had an effective result in preventing outbursts.
Pat Humphries, Newlands – You said the cleats in zones were more closely spaced in the vicinity of the outburst. Was there any evidence of this type of structure further outbye?
Dieter – I have only been at Central since July, 2001, so I cannot really comment about earlier workings. The cleats do occur sporadically in other parts of 310 and 311 panels, but they are not as well defined, as extensive and have irregular spacing. They were very prominent near the outburst.
Andy Mifflin, Oaky Creek – Can the cleats and other structures be detected by drilling?
Dieter – We _tilized_e all the drill logs. We are trying to keep the holes away from roof and floor and logging them in as much detail as possible. All significant features are noted.
Andy – We are drilling at Oaky North, but our drillers are not familiar with the conditions.
Rob Larkings, J. Rennie Ventilation – Is there any evidence of the tight coal which is experienced at Tahmoor?
Dieter – I only saw it at Tower. I have not seen it at Central.
Rob – What is the time required to drain the coal by drainage holes.
Dieter – 8 months.
Greg Nieuwenhuis, Kestrel – What was the logic behind the 8 m3/t selected as the threshold?
Ray Williams – 8 m3/t was chosen 8 years ago based on the desorption rate. With more data, it would seem that 7.6 would now be more appropriate. We had to satisfy ourselves the outburst did not occur from coal which had gas content of less than the threshold value. The structure zone had low permeability.
Paul Massarotto, Oil Company of Australia – Do you know the in-situ stress?
Dieter – Stress has not been measured for the underground area at Central. Borehole tests have been conducted away from the current workings. Close to disturbed ground there are significant changes of orientation)
Ray Williams – The bumps sounded like they came from the roof. They could have come from the coal. Bumps which precede an outburst indicate a change in volume. The water pressure drops instantly and the gas can then desorb and occupy the new volume which is generated. The outburst involved an 11 m length of coal. The big blocks of what were normally structured coal were pushed out by the gas.
Nick Gordon, Kestrel – The fault was of a different orientation to the usual structures in the area. Has drilling been modified to be able to pick up any repetitions of the structure?
Dieter – Flank holes are now drilled to cover them.
Richard Walsh, BHP Illawarra Collieries – Did gas contents increase away from the face? Was there monitoring of the drainage holes ahead of the face?
Dieter – All was as expected."

4. PERCEIVED SHORTCOMINGS OF CURRENT KNOWLEDGE

How well we understand outbursts is difficult to answer. The answer is a bit like the description of the elephant by 3 blind men. It all depends on the individual's viewpoint, pre-conceived ideas, knowledge and hopes. From the author's observations, the outburst knowledge of mining personnel and regulators varies considerably from well-versed to ignorant, although each individual's perception of his knowledge might, and probably does differ from his actual knowledge.

The geologist generally understands the geological setting of his mine, but is probably frustrated with the lack of real measurements of stress and strain: he is well aware that his knowledge is coloured in shades of grey. The engineer thinks more in terms of black and white, but there are many shades of grey in outbursts which must be born in mind when formulating and applying Outburst Management Plans. The miner generally has a lesser understanding and therefore more fear or bravado. Participation in mine outburst management committees by representatives from each discipline has been a very positive move.

The few outburst researchers in Australia have good understanding of and general agreement on the theory of outbursts as a consequence of their intimate associations with gas and outburst investigations and research over the last 20 years. However, they are very few in number and some are withdrawing from outburst research (willingly or unwillingly).

There is much known world wide about outburst theory, as illustrated by presentations to the 1995 International Symposium cum Workshop on Management and Control of High Gas Emissions and Outbursts in Underground Coal Mines and as summarized by Lama and Bodziony, 1996. Knowledge of outburst mechanisms in Australia has progressed in fits and starts and has been well documented (eg Proceedings Int Symp cum Workshop on Management and Control of High Gas Emissions and Outbursts in Underground Coal Mines, (Ed: R D Lama).

The various theories of how outbursts occur have been well documented by Lama and Bodziony, 1996, relevant extracts from which are included in Appendix 1.

Hargraves, 1958, defined an instantaneous outburst as:

 "....... the sudden disintegration of coal, and its projection from the seam, without deliberate initiation and accompanied by, and followed by enormous gas emission. The gas has the effect of carrying the broken coal for considerable distances. This projected coal is invariably of fine size. The gas pressures and volumes associated are sometimes sufficient to penetrate the intake roadways for considerable distances and to blow out stoppings. The outburst may be inadvertently set-off by some outside influence. Small proportion of outbursts occur when no work is going on at all. It may be an immediate reaction, outbursting suddenly and without warning, or it may be a series of minor bursts and readjustments culminating in an outburst, in which cases some warning may be received."

According to Gray, 1980, *"an outburst is the failure of coal and its ejection by stored potential energy being converted to kinetic form. This failure is associated with the release of seam gas."*

These two definitions are sufficient for this study.

There is a need to continually review and update the understanding of outburst mechanisms and to question safety procedures regarding outburst management. The following questions are relevent :

- What roles do coal mass strength, geological stress, abutment stress, gas pressure, water pressure etc play in the outburst mechanism?
- How do we know that the gas has been uniformly drained from the coal surrounding the entire length of a drainage hole?
- Could we replace or supplement current in situ gas content testing from coal cores by other, methods?
- What other, more efficient methods of gas pre-drainage can be utilized?
- In branched holes, how do we know that all branches have drained effectively?
- Can we be certain that a drainage hole has not crossed an impermeable zone which has not drained? Does it matter provided the zone is not wide and the coal inbye is drained?
- What causes impermeable zones?
- Does CO_2 make coal more prone to outbursts than CH_4?
- Can all personnel recognize when mining or geological conditions change from normal?

There are many other questions which remain unanswered and there are probably many questions not even thought of.

There is a high density of gas content tests in each mine, but each one is a snapshot in time and cannot necessarily be compared directly with adjacent samples. There is a severe lack of other relevant data such as measurements of gas pressure, gas pressure gradient, water saturation, coal strength, stress, etc. There is also a lack of time available to mine technical personnel to consider what measurements are required.

5.   CURRENT R&D PROJECTS AND START-UPS

Table 2 summarises in-seam drilling and outburst-related ACARP research projects conducted over the last 10 years. Total cost to ACARP of these projects was around $6.5M. Yearly committed expenditure is shown in Figure 1. Many projects failed because of industry apathy; Industry support is required for projects to succeed. Field trials or sample collection require mine site support. Many promising projects failed or did not meet their objectives because support was not received from mines, or the money was used up trying to seek support. With the ever increased cost cutting in mines, there is less opportunity now for a technical services officer at a mine to interact with and support researchers or their projects. This is discouraging researchers from working in the industry and is contributing to a lack of availability of solutions to industry problems.

The Australian coal mining industry is not a large enough market for manufacturers to fund outburst risk-reducing tools to service the industry. AMT manufactured a gas drainage hole shut-off valve and an open cut collision avoidance system, sinking a considerable amount of capital into the projects because the industry said it wanted them. Industry failed to buy the

product. Sigra and others have also experienced this apathy. Australian manufacturers of outburst risk management devices cannot afford to produce gear on spec.

Industry needs to accept ownership. The coal industry has, in the past, demonstrated it is innovative and can find solutions to its own problems. This has been well demonstrated in the field of in-seam drilling with respect to drilling accuracy and productivity over the last 10 years. Most problems have been solved in the mines with the support of service providers and manufacturers. This approach needs to continue with at least some people at the mines having time to think of technological solutions and having authority and budget to seek outside help as required. Practically all mine technical staff interviewed for this study and over the last 10 years complained of the lack of time and support to give in-depth thought to seeking solutions, let alone to support researchers in their investigations.

6.   OUTBURST RESEARCH NEEDS SURVEY

Two sets of questionnaires were sent to each potentially gassy mine to assess the current level of gas drainage and the requirements for research. Individuals throughout the industry who's email addresses are registered with the author (for distribution of information regarding ACARP gas and outburst workshops) were requested to complete a questionnaire on research needs. Most of the mines responded to the Outburst/Gas Survey 1 (Table 1) which was designed to provide a snapshot of the gas/outburst problem and the remedial/preventative action being taken. A total of 25 people responded to the ACARP Outburst Survey 2 which assessed research needs. The respondents are listed below along with the categories assigned to them for the summaries. Although there was a good cross section of the industry who responded, there were many experienced people whose opinions would have been appreciated but who did not respond.

Survey 2 Respondents
(the following classification codes are used: O=Operations, C=Consultant, R=Researcher, G=Government, E=Engineer, G=Geologist, S=Scientist, B=Bulli seam, Q=Queensland)

Ron Peace, Appin, OE	Abou Saghafi, RS
Gavin Taylor, West Cliff, OE	Paul Massarotto, REQ
Peter Wynne, Tahmoor, OE	Bob Newman, OEB
Sean Ewart, North Goonyella, OE	Andrew Filipowski, OEB
Anonymous, Queensland, OE	Ray Williams, CG
Mark Parcell, Southern, OE	Andrew Gurba, OGB
Marc Justin, South Bulga, OE	Rob Regan, GEB
Jeff Wood, OGB	
Bruce Robertson, OEQ	
Les Lunazewski, CE	
Gregor Carr, OEQ	
Peter Hatherly, RS	
Neville Stanton, OEQ	
Rob Jeffrey, RE	
Rod Doyle, OEB	
Andrew Lewis, OEQ	
Nick Gordon, OGQ	
Robert Larkings, GEB	

The responses to Survey 2 (Appendix 2) show that there are differences in perceived research needs between NSW and Queensland. In general, the following areas were seen by most as the highest priorities.

(The following codes indicate F=Fundamental Research, N=New Tools or Technology, A= Application of Technology).
The question number and the average response between 0 to 5 precede and succeed the description, respectively.

2.	Relative roles of gas, stress, strength, strain etc	F 4.2
50.	Central register of outburst related occurrences	A 4.2
49.	Regular (half yearly) gas/outburst seminars	A 4.0
30.	Detection of outburst prone structures in in-seam boreholes	N 3.9, A 3.9
13.	Scientific basis/validation of outburst indicator thresholds	F 3.7, N 3.2
15.	Role of permeability changes in outburst potential	F 3.7
23.	Differentiation between prone and non-prone structures	F 3.5
42.	Training of operators in outburst awareness and procedures	A 3.3
14.	Roles of mixed gases in outburst potential	F 3.4
16.	Measurement of gas make from holes during drilling	N 3.3
24.	Remote detection (non-drilling) of structures	N 3.3
17.	Measurement of gas make from holes during drainage	A 3.2
29.	Effects of cleat filling on drainability	N 3.2

Summaries for the raw data, Bulli seam operators, Queensland operators, and Researchers/Consultants are shown in the spreadsheets (Appendix 2)

7.   OUTBURST RESEARCH NEEDS WORKSHOP

The ACARP Outburst Research Needs Workshop held in Wollongong in February 2003 was attended by a cross section of the industry, representatives of the regulators and by leading researchers/service providers. The participants in the workshop demonstrated a wide range of experience and knowledge about outbursts.

The main outburst related issues facing the industry were determined as:
- Current outburst protocols, which seem to work reasonably well in the Bulli seam, might be giving a false sense of security in other geographical locations (eg Qld)
- Limited fundamental basis for current protocols (based on empirical conservatism)
- Appropriate barrier sizes (extension of holes beyond roadways)
- Some relevant O/B parameters not considered in O/B management – eg stress, strength, gas pressure, water saturation, etc
- Better understanding required for all stakeholders of outburst mechanism including roles of parameters such as stress, strength, gas pressure, etc
- Problems draining tight coal
- Problems drilling and draining highly stressed or broken ground

- Ambiguity regarding "structured coal" classification with respect to outburst thresholds

- Confident location of O/B prone structures
- Data acquisition inefficient and imprecise
- Poor predictive systems
- Becoming insular in our approach
- Training and awareness processes inadequate – learning not sustained

The workshop defined a set of requirements for the next 5 years:
- Validated and agreed understanding of outburst mechanism
  - Articulated
  - Relevant parameters and measurements
  - Understand the limits of application
- Tools to rapidly and efficiently reduce gas content/pressure (routine and last resort)
- Ability to identify different zones of O/B proneness/management with adequate response time
- Better means to negotiate high risk areas
- High confidence in defining structured areas and risk areas
- Develop methods to easily measure pressure gradients, stresses, strength etc
- Understand the discrimination of structure size/nature
- Develop permeability improvement tools
- Develop methods to drill and drain in highly stressed or broken ground
- Routine/reliable use of in-seam geophysics

The workshop's conclusions above essentially provided three primary goals that industry would like to achieve within 5 years.

Outburst Research Goal 1:
- Review and specify the outburst mechanism and the roles of the various parameters. The parameters must be practically measurable. Once the researchers have defined the mechanism, it will have to be communicated to all players.

Outburst Research Goal 2:
- Develop tools (methods) to rapidly, efficiently, and preferably practically reduce gas content/pressure as a routine and as a last resort.

Outburst Research Goal 3:
- Understand the (structural) conditions which cause zones of poor drainability or drillability and therefore, increase outburst proness, and to confidently locate these zones with adequate response time.

8. HOW TO ACHIEVE THE GOALS

To achieve the industry's goals, a combination of improved data collection and assessment, research and education is required. This will require extra effort, expenditure and ownership by industry over the next few years, but not to the same scale that is being expended now on trying to manage potentially outburst prone coal at some mines. It will also require a change of attitude by the regulators and cooperation with industry. Innovation needs to be encouraged rather than stifled as occurs at present. There is a dire need to fast track

development and commercialisation of necessary technology, especially IS approvals. The whole question of IS requirements for in-hole equipment should be re-examined.

ACARP can provide some funds and administer research, but there is a need for each mine to take ownership and responsibility for data collection, interpretation, documentation, research and development. In the last 10 years, ACARP has spent much industry money on research only to see industry ignore the results, or to complain that promised developments are not available to apply to today's problems. Each mine needs to support the developers of promising technology by providing trial sites, infrastructure, financial support and encouragement. Without this support, the developers will concentrate on other areas which will better pay their way (see the comments by Verhoef and Thomson in the next section and the comments by other developers in the notes from the Outburst Research Needs Workshop, February 2003).

8.1 Work Smarter Now

Mines can make changes to their practices through an improvement of outburst detection technology usage, to gain some immediate reduction of outburst risks. These changes should be possible to implement, but will add some cost to mining in the short term and will require some innovation by the mines and regulators. Stages of development of technology vary with some equipment only being at prototype stage. However, very few tools will be advanced to commercialisation unless mines sponsor them. The AMT survey tools which are industry standard were developed to their current level with considerable demand and support by BHP Collieries, but, according to Henk Verhoef, pers. comm.,

"AMT does not have any plans to start new R&D projects in financial year 2003/2004. AMT is interested in opportunities however they will have to be fully funded by external money. Our goal for this financial year is to create interest in and sell our DGS and to convert our underground DGS to a surface to in-seam tool and to commercialise the Collision Avoidance System. Due to lack of industrial interest in our CAS system and past delays in the certification process of the DGS, most of our R&D staff were retrenched about 18 months ago. There is no intention to increase our present staff levels. On top of this the compliance issues in regards to workplace certification is taking a lot of time. First of all we have to comply with ISO9001 and on top of this we have to comply with the Mines Departments workplace certification. This has an enormous impact on a small company such as AMT. Without this compulsary compliance there won't be an AMT. I believe our position is not unique in the industry. Compliance costs and significant delays in certification of products have a great impact on all small companies that provide the industry with probably 90% of the innovation and new products. The future for the inventors, innovators within the underground mining product companies is very bleak. Overregulation will kill off small established companies and prevent new start ups and therefore greatly reduce Australian content within the industry."

Scott Thomson, A.J. Lucas (2003, pers.comm.) stated

"I still think that getting more out of in-seam drilling is a priority (in terms of exploration data) but this needs a major overhaul – and it needs a commitment to supply IS logging instrumentation. ... The approach to our (A.J. Lucas) inseam drilling is governed by the primary requirement of gas drainage – little attention is paid to the quality of the exploration data supplied from this activity. Using RIM IV (which does appear to deliver improved

results) from horizontal drill holes would help significantly but we are a long way from having such a beast. Stolar are working on Iraqi bunker detection and land mines … they have little incentive to push too hard in coal. There may be an argument for an Australian initiative to take RIM IV into a horizontal drilling tool for our particular application – maybe ACARP would be interested in this?"

Some changes to procedures that can be made in the short term to improve data collection and to reduce outburst risk are suggested in the following sections. Detail is not provided and the list is not exhaustive, but hopefully, some thought might be stimulated. It is relatively easy for me, as author, to make the following suggestions when I am not faced with having to put out bushfires on a day to day basis. At present, much of the gas and outburst related work in the mines (other than gas content measurement and guided drilling) is manpower demanding, old fashioned and not as efficient as it could be. Changes could be made to improve efficiency and to free up minds for finding and applying solutions.

Suggested possible timing and approximate costs are shown in Table 3.

8.1.1 Monitored Drill Rigs

Fitting automated monitoring systems to all drill rigs with automated data collection is a first step to better management. Data monitoring should be included (and costed) in drilling contracts. Today's practice of relying on drillers to accurately record all variations in drilling of a hole is archaic. Some mines place much faith in their drillers' logs and ability to detect potentially outburst prone structures while other mines tell of many relevant structures which have been missed. Technological advances over recent years in IS computer technology should make the task achievable, or computers could be installed in flameproof enclosures on the drill rigs.

An appropriate technical officer would have to interpret the data collected, at least for the short term, but it should not be an insurmountable task to develop appropriate software to prepare hole logs of potential structures or hazardous zones. ACARP could fund a short term project plus a workshop to standardise data collected and data processing/interpretation. A coordinator would be required in the first year to help assess and interpret data.

8.1.2 Monitored Rotary Drilling

In higher risk areas, a monitored ProRam rotary drill (as developed by BHP under ACARP funding) could be used to test for structures up to say 100 metres in front of the face. I have been criticised by some for suggesting rotary drilling as most mines now use DHM drilling exclusively and see rotary drilling as a backward step. However, rotary drilling has been proven as being able to detect (by bogging) some structures that cannot be detected by DHM drilling. The BHP monitored ProRam successfully detected small structures at Appin that were the later focus of a small outburst (Danell, 1998). The main argument against rotary drilling is its lack of steerage. However, for many years prior to the introduction of DHM drilling, some drillers took pride in their ability to accurately drill rotary holes for exploration. With slow and cautious drilling with appropriate bottom hole assemblies, relatively straighter holes can be drilled and their trajectory can be determined by surveying. Sigra have partly developed a survey tool for recording during rotary drilling and downloading on withdrawal of the tool from the hole after completion of drilling. It will only be commercialised if there is a demand and support from the industry.

8.1.3 Drill Fluid Logging System

The Lunagas drill fluid logging system should be trialed to assess whether it can detect structures through changes in gas make during drilling. The proposed technology and equipment can be used for recognition of gas and gas-rock outburst prone conditions ahead of a driven heading face and along a drilled inseam hole. The underground version of the system consists of a drill rig, stuffing box, gas/water separator, gas flow and gas composition monitoring equipment, as well as IS computer and data logger. The expected output is a 'gas signature', which continuously monitors gas in drilling fluids and shows the changes in gassy conditions relative to the distance drilled.

8.1.4 Support for Development of Sigra Torque/Thrust/Survey for Rotary Drilling

Laboratory trials showed the Sigra torque/thrust device had potential for detecting strength changes in coal during drilling. The prototype was to be tested in a mine, but the project died for lack of mine support. The device holds good potential for detecting structures ahead of faces or for declaring coal to be structure free. Considerable work is required to advance the device to an operational tool. Ian Gray (pers. comm. July, 2003) advised

> *"Sigra has spent a huge sum on the development of drilling tools. This money has come in the form of four ACARP grants of total value $270000 to Sigra, a START grant of $190000 to Sigra and a grant of $234100 to the CMTE, part of which came to Sigra. In addition Sigra has spent $400000 of its own money. That is a total development cost of $1.1 million."*

> *"After this development we have a working:*
> ** Survey tool accurate to 0.15 degrees*
> ** A torque and thrust sensor which is known to provide good information on rock type and structures*
> ** A resistivity tool that needs further development but that seems to provide information on vertical location in the seam."*

> *"This combination can be assembled into two forms*
> ** A store on board rotary tool with torque and thrust sensor that can be used to detect faults, outburst prone structures etc whilst drilling. The tool will take a survey when rotation ceases. When the drill rods are pulled this tool can be downloaded to provide a drilling and survey log of the hole. This has huge potential within and without of the mining industry.*

> ** A geosteering tool for downhole motor drilling. Such a tool would have attached, the torque and thrust sensor and the resistivity probe. We believe the tool would solve the issue of staying in seam substantially."*

> *"We are determined to proceed with the rotary tool because of its commercial potential beyond coal mining. Our rate of development will be tempered by available funds and drilling opportunities we get. The tool has nevertheless extremely good potential in coal both in exploration drilling from surface and in finding faults underground. Either use will require a lot of drilling and learning as to what the torque and thrust outputs mean."*

> *"Our plan is to use the tool in surface operations. If it works well then we may be able to finalise the design and a decision will then be made as to whether to take it*

underground. This will depend on our assessment of the market. If coal drilling maintains its fixation on purely downhole motor drilling then we will probably not bother getting IS approvals."

"We still think that rotary drilling has a useful place in coal mining. We have shown that with a correct bit and stabiliser design, holes will stay reasonably straight and can be much more economic to drill than those with a down hole motor. Having a survey tool on board removes problems in finding out where the hole is."

"We can easily see another $200,000 going into tool testing and rock recognition algorithms. The availability of this money will control the rate of development."

"The real issue is how to test these tools. The figures described do not cover paying for a drill rig to stand by while we fiddle and fix bugs."

"If one looks at the history of our other successful developments then the effort on testing and refining the design has always been of equal or greater than that required to produce the prototype. The difference with our other successful developments is that we had the opportunity to do the testing."

8.1.5   Outburst and Gas Data Base Preparation on an Industry Basis

ACARP could fund one or two PhD students, preferably working together, to accumulate outburst and gas related data from each mine and from the GeoGas and BHP Billiton Illawarra gas laboratories, and to assess the data for similarities/differences. There is an abundance of gas data in the records of the mines and laboratories. With the appropriate agreements, the data could be collected in the one data base for assessment and interpretation by researchers as required.

8.1.6   Installation of Automated Flow Monitors

Mines could install automatic flow monitors on gas drainage holes and collate data for computer analysis. This will allow more efficient reservoir analyses and assessment of efficiency of drainage. Currently, flows are measured on a weekly basis providing a snapshot and taking up considerable manpower. Jeff Wood, 2003, reported *"Effective monitoring of the fluid system during drainage is required. We currently consider a threshold snapshot. We have no idea of the history leading up to any content test. There is much scope to improve monitoring of the drainage process from each hole to help understand and plan remedial work if necessary."* With today's technology, it is possible to automate the flow measurements with transfer of the data to surface via the mine's information highway. But no mine has applied the technology to gas flow monitoring or driven the IS development of the technology.

Ian Gray (pers. comm. July, 2003) commented:

"The initial project did not produce that effective a flow meter but subsequent work in house refined this to produce what we think is a workable device. This has been tried on Sigra's permeability test equipment at some length. The only underground trial was at Southern Colliery where units designed for test holes of 100 m length were fitted to

production holes 500 m long and were found to be wanting because they were at the upper limit of their flow range and because they were sufficiently small that large coal particles tended to block them."

"The lack of suitable electronics to record information from the flow meters led to the second project. At the end this provided an extremely good two wire electronic system for getting information from up to 255 nodes, each addressing up to five sensors (each flow meter has five sensors) over a 2 km cable. This system was built with considerable advice and support from BHP-Billiton Illawarra."

"The development took longer than was originally envisaged and some impetus was lost. The continued need for such a device in-house drove the development. What now exists is a flowmeter design that works under the uses that we have put it to. The electronics and software work but would need individual tailoring to suit each individual mine's data acquisition system. Above all it does not have IS approval yet."

"The impediments to its use are:
a) Lack of underground test of physical device in current form
b) Lack of IS certification
c) The lack of IS certification means that the electronics have not been tested in an underground environment
d) Cost of dovetailing software with mine data system
e) Cost of production for small production runs"

"The testing of the physical device could be easily overcome by us supplying a unit fitted with a manometer to a mine and letting it be used for a while. All we need for this is a mine that is prepared to install, read and observe the device."

"We have no doubt that the electronics will work underground. How willing will operators be to string a cable from flowmeter to flowmeter? and whether the cable will survive in a roadway? I would suggest that a set of dummy devices be set up and installed so that the mechanical issues can be identified. To do this will require a willing host and about $5,000."

"The next real issue is one of cost. Given that there are about 500 underground boreholes to be monitored in Australia and perhaps there is a 40% uptake rate for the new technology that leaves a market of 200 units which will have to be spread over about 3 flowmeter sizes, ie 70 odd units each. This is below mass production numbers and hand building would be required. Hand building means assembly differences and a need to calibrate each unit. Calibration costs money."

"Tailoring the software into each mine's data highway would cost about $25,000 and each flowmeter will cost $1,300. Our current assessment is that the industry does not want to pay this. If this is the case then the money required for IS certification is irrelevant."

8.1.7 Drilling of In-seam Holes Under Borehole Pressurisation

Mines could drill drainage holes using the Sigra borehole pressurisation system to
a) Maintain the hole stability during drilling and to reduce hole damage by slowly reducing in-hole pressure after drilling; and,

b) Collect multiple undesorbed cuttings samples from the hole for gas "content" testing.

Drilling in pressure-stabilised ground should reduce risk of loss of equipment down hole. This device also has the potential to enable drilling in difficult ground such as was experienced at Tower.

Ian Gray (pers. comm. July, 2003) advised:

"The tool still has the potential to enable samples of coal to be cut and sampled for gas content/sorption pressure from great length. It is a big piece of equipment (200 kg) that requires a special 12 m long standpipe to be used with it. It will almost certainly also require modifications once drilling experience is gained."

"The major issues barring the tool's use are:
- *Somebody has got to be prepared to test it*
- *The test technique is not a standard gas content test therefore it may not be accepted*
- *Contract drilling prevents innovation. Drillers make money drilling not testing equipment. Mines do not want to pay the standby test time.*
- *Come what may the tool will slow drilling but to less of an extent than pulling out and taking core."*

"If the industry did require the tool to be developed for their use then it should be prepared to make available a drill rig and crew for 4 weeks solid testing probably in blocks of one week at a time. In addition the likely cost to cover our time, modifications etc would be $150,000."

8.1.8 Cored Holes

Mines could drill a fully cored hole ahead of each developing face. Drilling parameters such as thrust pressure, rpm, water pressure, etc should be automatically recorded for indication of structures. The condition of the core should reflect the potential for outburst proneness, with poor core recovery generally indicating a hazardous zone. The core would also provide samples for testing of gas content, permeability and strength.

8.1.9 Dielectric Tool

A mine with CO_2 as the dominant gas could obtain approval to trial the CSIRO dielectric tool. This tool, in its earlier prototype form was shown to be able to detect mylonite zones in boreholes at West Cliff. It is in the prototype stage and ready for trials, but is not IS.

8.1.10 Piezometers for Pressure Gradient

Mines could install piezometers ahead of a development panel (from surface or in-seam holes) and measure the changes in fluid pressure as the face approaches, thus providing data on the gas pressure gradient. If an array of piezometers was installed, data could be gathered on directional permeability changes. Pressure gradient studies should be integrated with continuous gas flow monitoring.

8.1.11 Measurement of Change

When trying a new technique or new application of an old technique, it is essential to measure and monitor changes caused to the environment by the new technique. Without measurement, how can we know if the technique worked or failed? Many trials in mines are conducted on a suck-it-and-see basis without measuring the changes. Much of the perception of the success or failure of the trials is based on gut feeling rather than scientific measurement.

8.2   Definition of the Roles of Outburst Parameters

Lama and Bodziony, 1996, p 265, stated;

" ...the main factors that influence outbursts can be symbolically represented by the following function

OB = f(G,P,T,sigma)
Where;
G = gassiness of seam
T = Tectonics of the site
P = Properties of coal/rock
sigma = Stresses occurring in the seam or rock or part of seam "

"While the role of each of the factors will vary depending on local conditions, however, the greater the gas content and desorption rate, the lower the mechanical properties of coal and the higher the tectonic disturbances and stress, the greater the probability and size of an outburst. In outburst literature, gas and parameters that are associated with it such as gas content, sorption and desorption rate, type of gas, gas pressure, gas pressure gradient, etc have been studied in a much greater detail than other properties such as stress and strength properties of coal. "

Although the general understanding in the literature is that outburst proneness is dependent on gas content, gas pressure, gas composition, gas desorption rate, coal strength, coal permeability and stress among other factors, the Australian coal mining industry, for expediency, essentially bases its outburst management on gas content. This reliance on one index was criticised by Professor Antony Kidibinski during his visit to Australia in 1999 (Kidybinski, 1999) and by Harvey (2002). However, its success at preventing outbursts cannot be disputed. Outbursts have not occurred in the last 8 years when mining has been conducted in coal which was drained to below the threshold values.

8.2.1 Gas Content

Gas content testing has been developed to a stage where it is generally accepted. Most gas content testing for mining purposes is conducted using the quick crush method as applied by BHP –Billiton Illawarra Collieries and the GeoGas laboratories. Two ACARP projects have exhaustively compared the test results of the above two laboratories plus CSIRO and found that, although there are some minor quantitative differences between the laboratories for the gas content values quoted, testing within a laboratory produces consistent results. Gas content testing methodology has generally been well researched.

Although it has extensive proving by years of GeoGas experience, the GeoGas DRI 900 index should be verified by other labs or independent researchers. There is probably sufficient data available between GeoGas and BHP to use as a basis for a post graduate student study.

8.2.2 Diffusion Coefficients

According to Choi, 2003:

"The high nominal outburst risk for CO2 requires investigation of mechanism at a fundamental level to put it on a quantitative physical basis. This involves improved characterization of desorption and diffusion rates and relationship with coal fragmentation and particle size, and gas and coal maceral composition. High quality laboratory studies are appropriate here ... diffusion within the coal matrix can be quite different from the diffusion process in other porous material such as sandstone. There can be different distributions of micro-, meso- and macro-pores within the coal matrix in different coals, and the diffusion process can involve bulk diffusion, surface diffusion and Knudsen diffusion, also, capillary condensation can occur within the mesopores, and effects similar to molecular sieving within the micropores. Sorption kinetics can also influence the diffusion process. However, as a whole, CO2 is generally observed to desorb much faster than CH4."

8.2.3 Rapid Index

Gas content testing using the quick crush method requires a turnaround time of around 12 to 48 hours. With gas drainage planning, this time delay generally causes no problems. However, in cases where an urgent result is required for at-the-face decisions, the time delay is excessive. In these situations, a faster indicator might be useful. It could be argued that as mines get deeper and gas contents increase and permeability decreases, there is a need for continual monitoring of a gassiness index. There are many examples of rapid index tests in the literature, most having been developed in Europe. Two systems which have been tested in Australia are the Hargraves Emission Index and the Polish desorbometer. The former was developed by Dr Alan Hargraves and applied mainly at Metropolitan Colliery with some application at Leichhardt Colliery and Collinsville. The test was criticized by many for inconsistency of results. However, the inconsistencies were probably as much a function of the local geological variations and the attitudes of the samplers than of the technique itself. At Leichhardt, it was shown (Wood and Hanes, 1982) to give a good indication of the change from benign to outburst prone conditions. It then failed as the coal became wet. The method requires dry coal cuttings for accuracy. Dry cuttings could probably be obtained from wetter coal using a suction system or reverse air flow system to extract the cuttings through the drill rods. The simplicity of the device and testing technique would lend itself to automated testing from a purpose-built miner mounted drill rig.

The Polish desorbometer has been praised and used successfully by Dr Les Lunarzewski (pers. comm.) , but criticized for its inapplicability at West Cliff Colliery by Dr Ripu Lama (Lama, 1995). Further testing is required.

8.2.4 Gas Composition Change

Filipowski, 2002, showed that the degree of degasification of coal can be indirectly determined by measuring the amount of nitrogen in the emitted gas. He determined from many gas desorption tests that the gas content is indirectly proportional to the N2 proportion.

Measurement of N2 at the face or in a borehole should provide a rapidly assessable indication of the gas content.

8.2.5   What is More Dangerous - CO2 or CH4?

Do we have to ask? The literature generally indicates that CO2 causes more violent outbursts than CH4 and at lower gas content levels. However, recent modelling work by CSIRO (Choi and Wold, 2003) questions this paradigm. There is uncertainty amongst Australia's experts on the relative dangers, as expressed at the Outburst Research Needs Workshop. This question needs fairly urgent attention.

8.2.6   Gas Pressure Gradient

To effectively model outburst mechanisms, it is essential to understand the gas pressure gradient in the coal. Wood and Hanes, 1982 showed that outburst proneness at Leichhardt Colliery was directly proportional to the gas pressure gradient. A steep gradient accompanied outbursts. Modelling by Wold and Choi has supported this hypothesis. Other than from Leichhardt, gas pressure gradient data from Australian mines are lacking. Wold and Choi have resorted to 20 year old gas pressure gradient data from Leichhardt, but had other data such as gas pressure, strength etc from other parts of the Bowen Basin and Sydney Basin for their models. This is a pathetic situation. If we cannot or do not measure such important parameters, how can we expect to understand mechanisms?

8.2.7   Gas Pressure

Gas pressure testing ahead of a coal face by installing packers in in-seam holes is time consuming and interrupts production. It can also be dangerous. However, packer testing of in-seam holes can in some cases be replaced by installation of piezometers in holes drilled from the surface ahead of the face with automated monitoring of pressure changes as the face approaches the piezometer.

Application of pressurized drilling and collection of "virgin" state cuttings for desorption testing could indirectly indicate the gas pressure gradient. The drill pressurization system developed under ACARP funding by Sigra has not been used in a mine.

8.2. 8   Barrier Zones

How much of an area is drained by in-seam holes? What is the width of the zone on either side of a borehole or in front of the hole that is drained? Better definition of the borehole barrier zones is required, otherwise we cannot define the area drained. There is a considerable amount of data probably available in mines and with GeoGas which could be used in a study of barrier zones. This data should be evaluated and then a program designed to further test the drainage influence of holes drilled in a couple of test mines. Hole orientation, structure, permeability etc will have to be measured and considered.

8.2.9   Permeability

Permeability measurements are not typically conducted in surface exploration boreholes. Some companies have commenced conducting permeability tests in surface boreholes using

interference tests to assess directional permeability. This knowledge is essential for reservoir management, especially if areas of low permeability exist.

There is a need to correlate permeability measurements with structural geology mapping to better understand low permeability or impermeable zones.

8.2.10 Coal Strength

Coal strength is a prime parameter which should be considered in assessing outburst proneness. In the Bulli seam, it is accepted that most outbursts, especially those of large size are associated with soft or structurally disturbed coal. Some people believe that Bulli seam outbursts only occur from mylonite or sheared coal. However, a few relatively small outbursts have occurred in the Bulli seam in unstructured coal. At Leichhardt Colliery, most of the 200 plus outbursts occurred from relatively unstructured coal. One outburst of 300 tonnes had no shearing or faulted coal. The 500 tonne fatal outburst was associated with sheared coal. The coal was heavily cleated with major (+1m) cleat planes at 1 m spacings. The unconfined compressive strength was determined as 10 MPa and the tensile strength as 0.5 MPa.

But what do we mean by strength of coal and how can it be measured? Dr Ripu Lama was a recognised geomechanics expert who conducted much laboratory testing of coal and rock strength. Many different devices were used by him and others to try to characterize coal strength and to define changes in strength associated with outbursts. He expressed frustration with the inability of the various testing methods to give a reliable index of the coal mass strength. The coal mass strength in the mine face is the parameter we refer to as "strength" in the outburst or mining strain contexts, but how do we measure it? Taking a core or block sample and subjecting it to conventional UCS or tensile testing will yield numbers, but how reliable are the numbers for outburst assessment? The coal associated with the fatal 500 tonne outburst at Leichhardt was both "hard" and "soft". At the edge of the outburst, after clean up, the coal rib was "like basalt". Hitting it with a hammer caused a ringing noise. Yet high in the rib was fault gouge which could be scraped out with a finger. Alternating hard and soft coal zones were noted at Leichhardt in association with outbursts but were not satisfactorily defined.

Although conventional laboratory strength tests are required in outburst research to provide some sort of benchmark, other strength indices also should be measured which help define the resistance of the coal face to failure. There is a need for a simple field test which can indicate changes in coal seam mass strength during face advance and which can be reliably interpreted by people at the face.

The power drain by the head of the continuous miner is probably directly proportional to the overall strength of the coal being cut. Automated monitoring of power used by the continuous miner head with automated interpretation should provide a measure of coal mass strength and provide an alarm for change. If the face "hardening" which occurred at Leichhardt as a precursor of outbursts or face "softening" seen at other mines can be shown to be precursors of outbursts, then a miner-mounted power monitor should be able to be used as an alarm.

The Sigra torque/thrust device for use in drilling, if developed to a commercial tool should indicate changes in geological strength ahead of developing faces as would the BHP monitored ProRam drill.

8.2.11 Stress

In the literature, it is recognised that stress, or stress concentration in the face, plays a role in outbursts. In the Polish outburst formula, stress is calculated as a function of vertical lithostatic load multiplied by an abutment concentration factor (Kidybinski, 1999). At Leichhardt, the role of stress in mining strain and outbursts was well recognised and observable as intense mining induced cleavage. Similar mining induced cleavage was noted by the author in the early workings of Tower Colliery and at other mines. Geologists are not currently reporting the occurrence of MIC's. Are they not recognised or is the more efficient gas drainage reducing or changing the mining induced strain which used to result in outbursts?

Measuring stress in the coal face is very difficult and generally impractical. However, for modelling and defining the effects of stress in outbursts, some measurements will be required. In the past, stress orientation in the mines has been interpreted by some geologists from mining strain patterns (eg roof fall orientation, compressive shears in the roof etc) and some work was done by monitoring flat jacks for abutment stress change. More recently, stress change has been measured in roof strata. Measurements in coal are not simple, but should be considered.

8.2.12 Structure

There is little argument that most outbursts in Australian mines are associated with geological structures. However, the roles of the different types of faults or dykes are not clearly defined. There is little to be gained from European outburst experience regarding structure as most European outbursts occur in coal seams that can be considered as highly sheared or more intensely structured than Australian coal seams.

Zones of low permeability, poor drainability or poor drillability seem to be structurally controlled. The different individual types of structures (eg normal fault, thrust fault, strike slip fault, or dyke) do not appear to have much differences in proneness in general, however, it appears that where two different types of structures intersect, the difficulties with drilling or draining the coal increases exponentially. The mechanism is not understood. The cost of mining such zones increases exponentially and in some cases, the mine is abandoned as was the case at Tower Colliery.

Better understanding of the stress configurations which have produced the structures is required and an understanding of what combinations of structures cause impermeable or undrillable zones. If we cannot understand the underlying cause, we cannot overcome the problem.

8.2.13 Communication/Education

The half yearly Gas and Coal Outburst Seminar Committee seminars held in Wollongong help to keep mine personnel in the Illawarra thinking about outbursts. The notes from these seminars are distributed to players in Queensland. Over the last 9 years, there have been, on average, two ACARP sponsored meetings held per year in Queensland to help keep mine personnel similarly informed. These meetings have facilitated exposure of mine personnel to recognised gas and outburst specialists, but have not guaranteed transfer or retention of

knowledge. The Queensland meetings have been well attended by mine technical staff, but very poorly attended by mine management and the inspectorate. Respondents to the surveys indicated a high priority for continuing these seminars and workshops. There is some need to intensify outburst awareness in Queensland and an annual seminar should be dedicated to this purpose.

There is a call from the technical personnel at the mines for an outburst web site which could provide access to gas and outburst related literature and a forum for discussion and questions. Wollongong University Department of Mining Engineering has established a web site (Hutchinson, 2003) and unsuccessfully sought ACARP funding for 2004 to further develop the site. To get the most out of a forum, a facilitator will be required.

In the past, much of the conventional understanding of outburst mechanisms came from the extensive research conducted in Europe. In the 1980's and 1990's, Australian research, mainly by Ripu Lama, Alan Hargraves, Ray Williams, Ian Gray, Jeff Wood, John Hanes, Mike Wold, John Shepherd and others took the lead and culminated in the 1995 Outburst Symposium. Since then Ripu Lama has died, Alan Hargraves has experienced an incapacitating stroke and outburst research has slowed. Senior researchers and senior, outburst-experienced operators are approaching retirement age. The Chinese coal industry has been upgrading during the last 10 years or more and although China experiences outbursts, there is little known in Australia about them or about new Chinese outburst research. There is opportunity for cooperation between the two countries' coal industries. There is a need to renew contacts with gas and outburst workers in Europe and China.

8.2.14 Outburst Models

CSIRO modelling of outbursts has advanced significantly. There is now a need to develop better understanding of local conditions by preparing models for mines with outburst potential and for mines which historically experienced outbursts. These models can then be used to assess sensitivity of the various outburst related parameters.

To effectively model outbursts, a good data base is required. A data base should be established for each gassy mine, current and past. The data base should then be available for all researchers. Each mine should provide basic data on outburst potential and outburst parameters. These would include:

- Seam thickness, depth of cover;
- Structure description including cleat size, frequency, orientation, filling, faults, dykes, folding, etc;
- Roof and floor strata, lithology, thickness, strength;
- Coal information, proximate analysis, macerals, rank;
- Gas information, composition, content, pressure, pressure gradient, gas desorption pressure, water pressure, permeability, anisotropy, hole spacing, time for drainage, barrier width, etc;
- Mining - advance rate, support, etc;
- Stress, strain;
- Outburst history, descriptions of each outburst, photos.

8.2.15 Outburst Mining

One of the major obstacles to efficient outburst research today is the lack of outbursts. Most mines effectively degass so no outbursts occur. Where drainage is inefficient, the coal is either grunched (eg Tahmoor), abandonded (eg Tower) or avoided (eg Central). When there are appropriate researchers and technology available, an outburst prone zone should be thoroughly tested (gas content, pressure, pressure gradient etc) then conventionally mined using remote control with video recording of the event and continuous monitoring of changes (eg gas pressure gradient etc). The resultant data would yield a better understanding of outbursts and the video recordings could be used to educate mining personnel.

8.2.16 Outburst Awareness Training

The standard of outburst awareness training throughout the industry appears to be variable. In some mines the training is given by contractors, at others by the ventilation officer or geologist and at others by a deputy. Some of the training manuals I have seen are excellent. The question I ask is how good is the outburst knowledge of the trainers. It appears to be variable. If the blind lead the blind, the training value is very questionable. There is a need to standardise outburst awareness training and to examine knowledge retention through examination.

8.2.17 Outburst Research Advisory Committee

Since 1978, there have been two periods during which outburst advisory committees have operated. The first was established after the Leichhardt Colliery fatalities in 1978. It consisted of mines' technical representatives, regulators and researchers. Regulators from NSW and Queensland played leading roles. The main objectives were to promote knowledge acquisition and sharing and to coordinate the outburst research initiated under NERDDC funding. It eventually disbanded in the mid 1980's when outbursts in Australia seemed to be well under control – the Illawarra mines had introduced gas drainage with rotary drilling and Leichhardt and Collinsville Collieries were closed.

The second committee was established after the South Bulli fatalities in 1992. This was a smaller group formed as a sub-committee of a larger group. It consisted of Ripu Lama (KCC), Mike O'Brien (Shell Coal South Bulli), John Hanes (BHP) and Terry Sharky (Metropolitan - short term only). This committee disbanded when its chairman had to pursue other priorities.

After the West Cliff fatality in 1994, the NSW Chief Inspector tried to establish a committee to provide guidance to the industry and the regulators on outburst management. Representatives of two coal companies interpreted this as an attempt by the Chief Inspector to get industry to "do his job for him", and they did not cooperate. The Chief Inspector then issued a section 63 notice and the industry is still paying the price for lack of cooperation.

A committee was established in Wollongong to organise the 1995 International Outburst Symposium and has remained active. It now organises half yearly outburst seminars and acts as a de-facto outburst research guidance committee. It consists of Chairman, Bob Kininmonth, Les Lunarzewski, Jeff Wood, Chris Harvey, Ken Cram and John Hanes. There

is no formal committee which brings together outburst expertise for guidance or for definition of outburst research needs.

It is recommended that an outburst research advisory committee be established to guide outburst research over the next 5 years. Members should be funded by their employers, or by ACARP funding if they are small service providers.

8.2.18 Other Areas for Research

Some other topics for research include:
- Electromagnetic (EM) emissions as a precursor to outburst or similar activity (K. Vosoff);
- Borehole radar (W. Murray, CSIRO);
- Conductivity tool (W. Murray, CSIRO);
- Borehole shuttle tool for logging on completion of drilling with gamma, density etc (DMT, Germany);
- Micro seismic monitoring;, and,
- RIM, borehole to borehole.

8.3   Technology to Reduce Gas Content / Pressure

There is a need for tools (methods) to rapidly, efficiently, and preferably economically reduce gas content/pressure as a routine and as a last resort. There are zones in many mines which do not respond to conventional gas drainage drilling. There is an urgent need to develop and trial means of rapidly draining or reducing the gas content in these zones to the safe threshold level to prevent outbursts.

Over the last year or so, two mines at least have trialed hydrofracture to help degas tight seams. At Dartbrook, where sand propping was used, the technique was reported to work successfully. Hydrofraccing without propping was trialed at Tahmoor and the technique was reported to have failed.

Ian Gray believes that the Sigra borehole pressurisation tool would enable drilling of difficult zones. The methods being used to overcome the problem of poor drainage are prohibitively expensive. There is need for innovation, trials and sharing of knowledge. Some suggestions for trials based on Lama and Bodziony follow. Other methods need to be considered as well. Any trials should be thoroughly monitored and documented. Changes to critical parameters such as gas pressure and gas pressure gradient should be measured.

Consideration should be given to supporting mine personnel in post-graduate study. This could provide dedicated people for collecting, documenting and interpreting data. A method for sharing costs of trials amongst outburst prone mines and ACARP (outside of the normal annual approval process) should be developed.

8.3.1 Auger drilling

Holes 300 mm to 600 mm diameter were used for destressing and degassing the coal at Metropolitan Colliery in the 1970's and 1980's. Phillips and Green, 2002 reported that shotfiring the predrilled coal did not induce any outbursts. Trials of this technique in Australia have not included measurement of gas pressure changes associated with the auger

drilling. Destressing holes have been used successfully in Europe and Japan (Lama and Bodziony, 1996). A recent Australian trial was not accompanied by monitoring.

8.3.2 Hydrofracture

Hydrofracture technology is well advanced and available for underground trials. Trials need to include measurement of gas pressure changes caused by the hydrofracture.

8.3.3 Mylonite Erosion

Hargraves, 1995, trialled high pressure water erosion of mylonite and sheared coal at Kemira and Corrimal Collieries to prevent outbursts. If low permeability zones could be identified ahead of development faces, water jet erosion of the zones could be attempted as a degasification tool.

8.3.4 Blasting

Lama and Bodziony, 1996 define blasting or torpedoing as the most common method used in underground coal mines to increase flow rates and mine safety. The concept behind this is

"to destress the area so though that stress is transferred deeper ahead of the face or away from the coal seam.... In Russia, a 12 kg charge spread over 2.5 metre is a common practice in some seams. 2 - 3 such charges spread over longer distances in a hole are also fired. In a 15 hole blast design, each hole was 150 - 200 m long. CH4 flows increased by 30 - 40% over the four month period. ... Optimum hole length considered is 100 m and 2 charges of 25 kg each are suitably placed to increase permeability. On the average 130 kg of explosive per 1000 tonnes of coal mine is used. "

"In virtually all underground studies, no attention has been made to direct the blast so that it is more effective in creating flow rates. One of the main reasons why flow rates have not been high is the failure of the hole, which during uncontrolled blasting, causes local cracking only. ... studies on enhancement of permeability from explosive generated stress waves and expanding gases in the absence of a free face is very limited. Most of the work done in this area is in nuclear explosives or even early attempts of coal gasification, in-situ leaching and retorting of oil shales."

Recent experience by Tahmoor and Central collieries has shown that approved explosives for use in Australian coal mines are very difficult to source, especially in the short term. At Central Colliery which has CH4, it has been almost impossible to access permitted explosives. Perhaps in similar situations there is a potential to use other explosives by changing the environment in which they are used (Neil Tuffs, pers.comm. 2003). Perhaps with establishment of suitable barriers and injection of inertinising gas at the face to be blasted, it would be safe to use normally non-approved explosives. Affected mines could cooperate in joint purchase and storage of appropriate explosives.

Could explosives approved for surface use be used in surface to in-seam holes to increase permeability in areas isolated from underground mining? Could cavitation of surface to in-seam or in-seam boreholes be used to improve gas drainage?

8.3.5 Destressing Roadway

Mining in the Bulli seam has been shown to destress the underlying seams with a significant increase in permeability in the underlying seams. Lama and Bodziony, 1996, report the use of a destressing heading driven in the roof rock, 5 to 10 m above the coal seam. Roadways driven in the coal under the stress relief roadway experienced reduced gas pressure, flow and stress, especially around faults. 250 mm diameter stress relief holes drilled from the rock road enhanced the stress relief. In Donglin Colliery (China), outbursts were prevented by drilling 300 mm diameter stress relief holes in another coal seam 6 m above.

Bruggemann and Tuffs, 2003 reported on the use of a drivage of a roadway in roof stone above coal that would not drain.

8.3.6 Chemical Treatment of Coal Seam

Lama and Bodziony, 1996 reported that the chemical treatment of coal seams is based upon the injection of fluids which help increase permeability by dissolving some of the mineral matter deposited on the cleat surfaces of coal. Studies by Lila and Andrew Gurba, 2002, have shown that the cleat in low permeability in Australian coal are essentially cemented with carbonates. Injection of hydrochloric or other acids should dissolve the carbonate producing CO_2 and water. Robertson, 2003 reported that laboratory tests of acid injection for use at Dartbrook indicated that an increased permeability would be obtained, but there would be increased amount of CO_2 released into the returns.

Lama and Bodziony, 1996 reported that hydrochloric acid treatment of coal seams acts basically by increasing the macroporosity. It can increase the gas permeability of impermeable seams by a factor of 4 - 9, gas liberation by a factor of 2 - 3 and the radius of influence of the degassing seam borehole by a factor of 2. Laboratory studies on coal samples conducted by CSIRO have shown that permeability of coal samples after treatment with acids increase by two orders of magnitude. The main problem seems to be getting the acid to the source of the problem.

There is a need to further trial this technique with documentation and sharing of knowledge.

8.3.7 Electro-hydraulic Fracturing

Lama and Bodziony, 1996 reported that

"the electro - hydraulic technique depends upon the conversion of electrical energy into mechanical energy in the presence of a fluid as a result of the shock impulse of high energy. In a borehole filled with water and subjected to an electrical discharge, high pressure develops. Development of an impulse in the hole filled with water with the electrical discharge generates a dense low-medium gas pressure pulse. This causes shock waves in the medium resulting in the development of new cracks and extension of existing tracks."

"Laboratory and field tests of electro-hydraulic effect show the possibility of increasing gas emissions and increasing the effectiveness of early drainage. "

8

8.3.8 Water Injection

According to Lama and Bodziony, 1996 water injection is one of the common methods used in Bulgaria, China, France and Canada.

"The principle of the method is to increase the moisture content of the coal seams which does not allow rapid desorption and at the same time forces the methane gas out from the coal. ... under low permeability conditions, pumping pressures up to 15 MPa have been used with slow pumping rates over 20-25 days with hole spacing of 2 m. ... it is considered the water injection is not successful in seams with carbon dioxide. The arguments advanced are the injection of water at high pressure will increase the pressure of gas in the micro-crack system and with the development of cracks, it may cause an outburst. "

9.   CONCLUSIONS

The main outburst issues facing the industry (as determined by the Outburst Research Needs Workshop) were:

  n) <u>Current outburst protocols</u>, which seem to work reasonably well in the Bulli seam, might be giving a false sense of security in other geographical locations (eg Qld);
  o) <u>Limited fundamental basis</u> for current protocols (based on empirical conservatism);
  p) <u>Appropriate barrier sizes</u> (extension of holes beyond roadways);
  q) Some <u>relevant O/B parameters</u> not considered in O/B management – eg stress, strength, gas pressure, etc;
  r) Better understanding required for all stakeholders of <u>outburst mechanism</u> including roles of parameters such as stress, strength, gas pressure, etc ;
  s) Problems draining "<u>tight coal</u>";
  t) Problems drilling and draining highly <u>stressed or broken ground</u>;
  u) Ambiguity regarding "<u>structured coal</u>" classification with respect to outburst thresholds;
  v) Confident <u>location of outburst-prone structures</u> (are some structures actually more outburst prone than others?);
  w) <u>Data acquisition</u> inefficient and imprecise;
  x) <u>Poor predictive systems</u>;
  y) Becoming <u>insular</u> in our approach; and,
  z) <u>Training and awareness</u> processes inadequate – learning not sustained

Other issues are:

  • Outburst mangement by the Australian coal industry is expensive, and although it is generally effective it is not very cost efficient.
  • In recent years, five outbursts have been recorded. Four of these occurred as failures of Outburst Management Plans. Nobody was killed or injured.
  • Current outburst management is based on only one parameter - gas content. This is poor science.
  • Many ACARP funded research projects have failed to achieve their objectives, partly because industry did not take ownership and did not provide the projects with field trial support.
  • There is desparate need for reliable detection of potentially outburst-prone structures

during drilling. Mines need to adopt monitored drilling and ACARP should provide support for further development and trials of the Sigra torque-thrust tool and the CSIRO dielectric tool which offer the best potential for structure detection.

- Research has proven challenging when outbursts are actively avoided in mining.
- The lack of time for technical personnel to think, analyse etc is a symptom of one of the prime problems facing outburst management and other technical aspects of mining.
- The current gas content thresholds have been successful in preventing outbursts on conventional development faces and nobody has been killed by an outburst since 1994. But it is not known if thresholds will prevent outbursts when mining conditions change from the present conditions.
- There is a high density of gas content tests in each mine, but each one is a snapshot in time and cannot necessarily be compared directly with adjacent samples. There is a severe lack of other relevant data such as measurements of gas pressure, gas pressure gradient, water saturation, coal strength, stress, etc. The roles played by these factors must be more closely defined in order to better understand outbursts.
- There is a need to continually review and update the understanding of outburst mechanisms and to question safety procedures regarding outburst management.
- There is a need for tools (methods) to rapidly, efficiently, and preferably economically reduce gas content/pressure as a routine and as a last resort.
- Approved explosives for use in Australian coal mines are very difficult to source, especially in the short term. Thus the use of explosives for grunching in areas which cannot be adequately drained is not viable.

10.   RECOMMENDATIONS

The Outburst Research Needs Workshop produced a set of requirements for the next 5 years which should be given high priority:

a) Validated and agreed understanding of outburst mechanism;
  - Articulated
  - Relevant parameters and measurements
  - Understand the limits of application
b) Tools to rapidly and efficiently reduce gas content/pressure (routine and last resort);
c) Ability to identify different zones of O/B proneness/management with adequate response time;
d) Better means to negotiate high risk areas;
e) High confidence in defining structured areas and risk areas;
f) Develop methods to easily measure pressure gradients, stresses, strength etc;
g) Understand the discrimination of structure size/nature;
h) Develop permeability enhancement tools;
i) Develop and trial methods to drill and drain in highly stressed or broken ground; and,
j) Routine/reliable use of in-seam geophysics.

There are three primary goals derived from the above research and development requirements:

Outburst Research Goal 1:

Review and specify the outburst mechanism and the roles of the various parameters. The parameters must be practically measurable. Once the researchers have defined the mechanism, it will have to be communicated to all players.

Outburst Research Goal 2:

Understand the (structural) conditions which cause zones of poor drainability or drillability and therefore, increase outburst proneness, and to confidently locate these zones with adequate response time

Outburst Research Goal 3:

Develop and apply tools (methods) to rapidly, efficiently, and preferably economically reduce gas content/pressure as a routine and as a last resort.

The following recommendations, developed during this study, will help achieve these goals:

1) High priority is required to address the need for awareness development, eg continuing gas and outburst seminars, a web site with papers on gas and outbursts and a forum for active discussion and debate and refinement of procedures. It is recommended that ACARP approve out-of-round funding for the Wollongong University Outburst web site at least as an interim measure.

2) To improve the reliability of structure detection in the shorter term, mines should investigate and implement where locally appropriate:
   a. The use of automated drill rig monitoring on each drill rig with data analysis by a competent professional,
   b. The use of a monitored rotary drill such as the BHP/ACARP developed monitored ProRam,
   c. Support to commercialisation and trial of the Sigra torque/thrust tool,
   d. Trial of the CSIRO dielectric tool,
   e. Trial of the Lunagas/AMT drill fluid logging system,
   f. Trial of the Sigra borehole pressurisation system and cuttings sampler, and,
   g. Installation of piezometers or packers ahead of a mine face to demonstrate that gas pressure gradients are benign; the pressure gradient should be known if development rates are to be optimised.

3) Mines should work with researchers to collect basic data on the importance of many factors including coal seam structure, strength, gas pressure, pressure gradients, stress, strain, etc. Each mine needs to support the developers of promising technology by providing trial sites, infrastructure, financial support and encouragement.

4) To improve detection of structures during drilling, ACARP should encourage and fund rapid development and testing of the Sigra torque-thrust tool and the CSIRO dielectric tool.

5) The industry should consider the value of an experimental outburst mine. Financial support and encouragement should be given for a gassy mine to collect appropriate data, and to provide sites for applied research and trials.

6) A coordinated approach to data collection and research is required. A coordinating committee should be formed, made up of recognised gas and outburst "experts", senior industry representatives and regulators from NSW and Queensland to guide outburst research over the next 5 years.

7) Post graduate education of mining engineers and geologists working in the industry should be actively encouraged by ACARP and mine management to support succession of gas and outburst professionals.

8) A change of attitude by the regulators and cooperation with industry is required. Innovation needs to be encouraged rather than stifled. Representatives of the Queensland inspectorate should actively participate in gas and outburst workshops, as their colleagues in NSW do.

9) The whole question of IS requirements for in-hole equipment should be re-examined.

10) There is some need to intensify outburst awareness in Queensland and an annual seminar, involving management, technical staff, workforce and inspectorate should be dedicated to this purpose.

11) Contacts with gas and outburst workers in Europe and China should be re-established.

12) Outburst awareness training should be standardized and examination of knowledge retention should be conducted.

11.   ACKNOWLEDGEMENTS

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TABLES

Table 1 ACARP Outburst/Gas Survey No1

	Mine Outburst Management Survey						
1	**Mine Name**	**Appin**	**West Cliff**	**Tahmoor**	**Metropolitan**	**Springvale**	**Central**
2	Seam	Bulli	Bulli	Bulli	Bulli	Lithgow	German Creek
3	Depth of Cover Seam Thickness (m)	500 m 2.8m	450 -500 m 2.8 m	350 – 450m	2.8 – 4.0m	300 – 400m	400 – 430m 1.9 -2.7m
4	Virgin gas content (m3/T)	10-12	14 - 15	11 - 13	12 – 16	0.24	16
5	Drained gas content (m3/T)	2-4				0.24	2 – 4
6	Gas Composition (CH4% / CO2%)	95 / 5	95 / 5	5 - 15 / 85 - 90 recently, 50/50 over next 10 yrs	0 -70 / 100 – 30	13 / 87	97/3
7	In-seam drilling per year (m)	35,000	120,000	75,000		0	50,000
8	Gas drained per year m3		54,211,000 - pure CH4	92,000,000		0	31,000,000

	Outburst Controls						
9	Is an Outburst Management Plan used?	Yes	Yes	Yes	Yes	No	Yes
	Which of the following controls are used routinely ?						
10	Across panel drilling - Single (S) or Branched (B) holes?	B	B	B	S	No	S
11	Flank drilling (guided)	Sometimes	Yes	Yes		No	Yes
12	Flank drilling (rotary)	Sometimes	Yes	Yes		No	No
13	Surface to in-seam flank holes	No	Yes	No	No	No	No
14	Face gas monitoring	Yes	Yes	Yes		As required by CRMA	Yes
15	In-seam drainage hole flow monitoring (measurement frequency)	2 weeks	Weekly	2 weeks		No	Weekly
16	Microseismic monitoring of face	No	No	No		No	No

Mine Name	Appin	West Cliff	Tahmoor	Metropolitan	Springvale	Central
Outburst Controls (contd)						
17 Premining gas content sampling (provide sample spacing)	Not always	150 m, 10 m either side of structures	100 m max	50m	Yes 750m+	Worst case
18 Face gas content sampling (provide sample spacing)	Yes	?	No		No	No
19 Personnel training in recognition of O/B precursors	Yes	Yes	All development crews, 6 monthly	Yes	No	Yes
20 Grunching	No	No	Yes, coal which will not drain	As required	No	No
21 Other - please specify.	Hole spacing decided from geology and experience				No	Will mine through roof strata over O/B zone

	Effectiveness of Outburst Controls						
22	Have any outburst related phenomena occurred in the last 2 years?	Yes	No	No	No	N	Yes
	If "Yes", for each occurrence:						
23	Coal displaced	Very small in 406 - 2T					
24	Gas displaced						
25	Length of cavity	1m					
26	Method of mining (eg video-controlled remote, normal, grunch)	Normal					
27	Records kept (maps, photos, analyses, reports)						
28	What precursors were noted?						
29	Are any areas resistant to drainage?	Yes	Yes	Yes	Yes		Yes

Mine Name	Appin	West Cliff	Tahmoor	Metropolitan	Springvale	Central
Special Outburst Related Problems						
Are there any problems that require research attention?	Drilling boggy areas, improve drainage in difficult areas	Gurba microscopy current	Gas content thresholds too low. Have spent $10M's trying to drain coal which would probably never outburst.		Western Coalfields contain much water. Research into permeability changes in coal and roof due to mining and effects on fluid flow will benefit gas and water management.	
Please specify.						
Can mine name be specified in summary or is anonymity required?	Yes	Yes	Yes	Yes	Yes	
	Ron Peace, Drainage Engineer	Gavin Taylor, Manager	Peter Wynn, Manager	Alan Phillips, Wayne Green	Rae O'Brien, Sr Mining Engineer	

Mine Outburst Management Survey						
1 **Mine Name**	**Southern**	**Anonymous**	**Newlands**	**North Goonyella**	**Moranbah North**	**South Bulga**
2 Seam	German Creek	German Creek	Newlands	Goonyella Middle	Goonyella Middle	Whybrow
3 Depth of Cover / Seam Thickness (m)	140 – 220m	180 – 250m 1.8 - 2.4m	260m 5.7 – 7.2m	250m 6.5m	250 – 400m	40-300m 2.2 - 2.9m
4 Virgin gas content (m3/T)	2 - 9	8 - 9	7 max	8 - 12	4 (later 14)	0 - 7
5 Drained gas content (m3/T)	<5.75	<6	2.5	2 - 6		3
6 Gas Composition (CH4% / CO2%)	95 / 5	96 / 4	100 / 0	94 / 1-2	100/0	95 / 5
7 In-seam drilling per year m	13,500(2002) - 25,000(2003)	20,700	8,000	22,000	0	6,600
8 Gas drained per year m3		10,100		34,000,000	0	7,700,00

Outburst Controls

9 Is an Outburst Management Plan used?	Yes and No - drainage for frictional ignition prevention	Yes	Yes	Yes	To be developed	No
Which of the following controls are used routinely:						
10 Across panel drilling (Single or Branched holes?)	S	B	S	S	No	
11 Flank drilling (guided)	Occasionally	Yes	As required	No	2 Surface to IS	
12 Flank drilling (rotary)	Rarely	No	No	Yes - as required	No	
13 Surface to in-seam flank holes	No	No	Yes	No	Yes	
14 Face gas monitoring	Yes	No		Yes - Trolex		
15 In-seam drainage hole flow monitoring (measurement frequency)	Weekly	Monthly	Weekly	4 daily		
16 Microseismic monitoring of face	No	No		No		

	Mine Name	Southern	Anonymous	Newlands	North Goonyella	Moranbah North	South Bulga
17	Premining gas content sampling (provide sample spacing)	Depends on drainage	Depends on drainage and structures	Surface holes	Yes - 50m	Surface holes	
18	Face gas content sampling (provide sample spacing)	No	No	No	No		
19	Personnel training in recognition of O/B precursors	Yes	Yes	Yes	Yes	Yes	
20	Grunching	No	No	No	No	No	
21	Other. Please specify.						

	Effectiveness of above						
22	Have any outburst related phenomena occurred in the last 2 years?	No	No	No	Yes	No	No
	If "Yes", for each occurrence						
23	Coal displaced				2T		
24	Gas displaced				Negligible		
25	Length of cavity				1 - 5 m		
26	Method of mining (eg video-controlled remote, normal, grunch)				Normal		
27	Records kept (maps, photos, analyses, reports)				Photos, report		
28	What precursors were noted?				Increased gas, drippers		
29	Are any areas resistant to drainage?	No			Yes		No

Mine Name	Southern	Anonymous	Newlands	North Goonyella	Moranbah North	South Bulga
Special Outburst Related Problems						
Are there any problems that require research attention?		Prediction of variability of gas content and drainability		Appropriate desorption rate indices and barrier widths for Queensland coals.		
Please specify.						
Can mine name be specified in summary or is anonymity required?	Yes	No	Yes	Yes	Yes	Yes
	Mark Parcell, Dep. Manager		Michael Barker, Tech Serv Super	Sean Ewart	Guy Boaz, Mining Engineer	

Table 2 ACARP funded Gas and Outburst Research Projects

No	Title	Comments – J.Hanes	Completion date	Value	Who
1993					
C3023	Design Optimisation of Longhole Drilling Equipment	Good project. Defined limiting factors for drilling and ways to overcome them. Only Appin using rotary slide as recommended. Longyear developed new rods.	07/25/94	70,000	SIMTARS
C3029	Improved Technology for Maintaining Hole Integrity During Gas Drainage	Big report by Ripu. Too tecnical for most and therefore practically ignored.	01/08/96	25,000	Austral Coal
C3030	Real Time Monitoring of Gas Emission		12/20/96	135,000	Austral Coal
C3034	Development of a Gen Purpose Hydrogen Monitor		10/07/94	80,000	Uni of NSW
C3035	Improved Remote Control and Monitoring of Outburst Mining Equipment	Good demo. Gone nowhere since.	06/09/95	170,000	Austral Coal
C3040	Commissioned Study to Set Research Parameters for Long Hole Drilling	Start of communication meetings which have persisted.	12/09/93	50,000	J & SD Hanes
C3070	In-Seam Drill Monitoring and Bit Location System (Stage 1)	See comments for stage 3	07/10/95	235,000	BHP
C3071	Caliper Probe For Logging In-Seam Boreholes	Probe developed & worked, never incorporated into drilling.	03/05/98	41,680	ACIRL
C3072	Borehole Pressurisation System	Successfully developed, but not tested U/G due to apathy of mining companies	09/05/98	144,490	Sigra
C3073	Bit Torque, Load and RPM Sensors	Developed. Good potential. Incorporated in Sigra geosteering tool.	11/05/97	83,620	Auslog
C3074	Standards for In-Seam Drilling Equipment	Small step for developing IS gear.	08/04/95	11,130	Auslog
C3075	In Seam Drilling Project Coordination	Continued communications meetings	02/09/95	40,000	J & SD Hanes
C3076	Real Time Return Gas Monitoring For Outburst & Gas Drainage Assessment	Seemed to work well, but nobody seems to be using the system.	08/08/97	91,164	GeoGAS
C3077	Gas Detection Technique & Equipment to Continuously Monitor Gas In Drill Fluid	The gear was developed, but not put into action due to lack of interest by miners.	09/08/94	45,000	Lunagas
C3079	Workshop on Management and Control of Outbursts in U/G Coal Mines	1995 Symposium and Workshop on Gas and Outbursts. Good dissemmination info.	05/11/95	25,000	Austral Coal
				1,247,084	

1994					
C4033	Stimulation of Gas Make from Horizontal In-Seam Drain Holes in Hydraulic Fracturing	Not being used	02/04/00	122,535	CSIRO Petroleum
C4034	Outbursting Scoping Study	Ripu produced the book which gives good summary of outburst/gas knowledge.	05/14/96	50,000	Austral Coal
C4035	Co-ordination of In-Seam Drilling Research	Continued communications meetings	02/08/96	44,000	J & SD Hanes
C4036	In-Seam Drill Monitoring and Bit Location System Stage 2	See comments for stage 3	09/03/96	250,000	BHP
C4037	Sensing and Logging for In-Seam Boreholes	Developed gamma sensor, not useful for roof prox, but might be OK for horizon control. In geosteering tool CMTE/Sigra	01/09/97	210,000	CMTE
C4038	Electronics for Bit Torque, Load and RPM Sensors	Successful.	11/05/97	20,000	The AGA Consortium
C4040	Development of a Hydrogen Monitor for Use in Coal Mines		10/05/97	139,253	Uni of NSW
				835,788	
1995					
C5027	Co-ordination of In-Seam Drilling Research	Continued communications meetings	05/15/97	44,000	J & SD Hanes
C5028	Waterjet Assisted Drilling of In-Seam Cross Panel Methane Drainage Holes	Not successful.	06/13/97	195,000	CMTE
C5029	Geosteering/Sensing Tool for Downhole Motor and Rotary Drilling	The tool has been developed and tested in a surface hole. Will need a champion to get testing U/G then IS approval.	Current	234,100	CMTE
C5030	The Development of a Gas Drainage Flow Meter	Successful, but industry not using it.	09/05/97	99,000	Sigra
C5034	Development of the Borehole Pressurisation Tool for Outburst Assessment	Has good potential for less expensively testing gas content etc ahead of face as outburst etc indicator. Needs U/G testing, but no champion and stalled.	Current	156,850	Sigra
C5035	Prediction of Outbursts in U/G Coal Mines Based on Radon-222 Anomaly	Have not heard anything. BHP championed.	09/05/98	79,500	ANSTO
C5036	Modelling Study of Hydraulic Fracturing for Gas Drainage		04/10/97	24,408	CSIRO Petroleum
C5037	Degassing of Methane and Carbon Dioxide: Prediction of Gas Composition		12/04/98	116,371	James Cook Uni
				949,229	

1996					
C6020	Mine Gas Control Technology Transfer W'kshops	Completed	01/05/02	25,000	CSIRO Explor. & Mining
C6021	Automatic Valve for Immediate Shutdown of Gas Capture from Underground Source	Developed. Good potential. Industry apathetic.	03/05/98	40,000	Lunagas
C6022	Gas Drainage Borehole Shut Off Valve	Ditto. Requirement of Moura findings.	07/02/99	93,250	Sigra
C6023	Comparison of Quick Crush Techniques	Showed that the industry standard had problems.	12/04/98	76,250	CSIRO Energy Tech
C6024	Outburst Mechanisms: Coupled Fluid Flow - Geomechanical Modelling of Mine Development	Very good model for understanding O/B factors.	02/04/00	100,000	CSIRO Petroleum
C6025	Precursors & New Understanding of High Gas Emissions & Outbursts through Seismic Monitoring	Good potential shown, but outbursts and emissions not montiored.	12/04/98	65,000	CSIRO Explor. & Mining
C6026	Borehole Dielectric Probe for the Detection of Mylonite Zones and Other Structures	Good potential but needs industry to push development	08/02/99	130,000	CMTE
C6027	Co-ordination of In-Seam Drilling Research	Continued communications meetings	05/05/98	44,000	J & SD Hanes
C6028	Long Hole Water Jet Assisted Drilling	Not successful.	11/05/99	240,000	CMTE
C6029	In-Seam Drill Monitoring (Stage 3)	Developed the only drill monitor available. Clearly detected structure which later had outburst. Inexpensive. Complete industry apathy.	10/05/99	75,000	BHP
C6031	Production Implications of H2S		06/02/00	162,000	Uni of Queensland
				1,050,500	
1997					
C7022	Co-Ordination of In-Seam Drilling Research	Continued communications meetings	07/02/99	44,000	J & SD Hanes
C7023	Demonstration of Bit Torque, Load, RPM and Survey Tool	The best potential for detecting structures, but no miner will provide test site.	Died	96,850	Sigra
C7024	High Spd Flex. Hose CrossPanel Drilling System	Potential demonstrated. Needs champion	01/05/00	200,000	CMTE
C7038	Commerc. Version of Autom. Shut Down Valve	Another good tool, but industry apathy rules.	07/02/99	60,000	Lunagas
				400,850	
1998					
C8003	Coordination of In-Seam Drilling and Gas/Outburst Research	Continued communications meetings	04/05/01	60,000	J & SD Hanes
C8021	Data Handling for Gas Drainage Flowmeters	Hardly worth the effort if industry will not use it.	Died	90,800	Sigra

C8023	High Speed Cross Panel Drilling System	Will industry use another drill system?	06/05/01	195,903	CMTE
C8024	Improved Reliability of Fast Desorption Gas Content Measurements	Hopefully will give an indication of where to go next. Delays due to difficulties getting U/G samples	Current	154,280	BHP
				500,983	
1999					
C9020	Long Hole Waterjet Drilling for Gas Drainage	Difficulties getting test sites. Did not meet objectives	Current	111,000	CMTE
C9022	Application of Infra Red Methane Measurement		Current	147,170	Uni of NSW
C9023	Numerical Modelling of Outburst Mechanisms and the Role of Mixed Gas Desorption	Continuing good modelling which will help understand O/B's. Main data input is from Wood and Hanes, circa 1982. Miners not gathering the required data.	Current	65,000	CSIRO Petroleum
				323,170	
2000					
C10005	Financial/Technical Audit of C5029 and C7023	Projects delayed because of lack of mine support ie test sites.	Completed	11,000	BHP
C10008	Improved Application of Gas Reservoir Parameters	Project completed	Current	128,327	GeoGAS
C10011	Gas Drainage Efficiency Improvement	Good science.	Current	150,000	AGURBA
C10012	Coordination of In-Seam Drilling, Gas & Outburst Research	Continuing communication re gas and outbursts. Extended to OB Scoping Study	Current	100,000	J & SD Hanes
C10016	Drilling Technologies for Soft & Low Permeability Coals	Difficulty getting test site.	Current	138,000	CMTE
C10027	3D Perm Characterisation of Large Coal Samples	Project completed	Current	135,000	University of Queensland
				662,327	
2001					
C11030	Variability of Coal Seam Parameters as they Impact on Outbursts	This modelling work should be supported, but better input data required.	approved	290,000	CSIRO Petroleum
C11057	Gas Drainability and Outburst Risk Assessment	There is a need to extend the micro to the face environment.	approved	122,000	AGURBA
				412,000	
2002					
C12024	Comp. Study of In-seam Surveying Technology		Current	150,000	CMTE Development Ltd
C12062	Fracture Toughness as a Replacement for HGI	Might have spin-off application to coal seam strength	Current	19,500	CCSD
				169,500	
			Total	*6,551,431*	

Table 3 Possible Progression of Research

Task \ Quarter	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	Cost ? $000 ACARP	$000 Mine (per)
ACARP Appoint Coord'r	*																												300	
Monitor DHM drill rigs																														
Reports by experts - what to monitor	*	*																											10	
Suppliers design rig modifications			*																										10	
Mines (2) have trial rigs modified to monitor				*	*																									20
Develop software for data process/interpret			*	*	*																								25	
Rig monitoring commence					*																									10
Workshop to assess data						*																							5	
Standardisation of monitors, data etc						*	*																						10	
Mines standardise rig monitoring								*																						
Monitor Rotary Drilling for Structures																														
Adapt ProRam for monitoring trial (?Tahmoor)	*																												10	
Collect data ahead of faces - interp BHP software		*																												10
Report initial data and interpretation		*																											10	
Workshop on straight rotary drilling techniques			*																										5	
Adopt in OB prone mines for structure free proof			*	*	*																									10
Trial Coring of Face Holes																														
Select experienced contractor	*																													
Determine core test requirements (experts)	*																												10	
Fit monitor system to drill rig		*																											10	
Drill trial hole at OB prone Bulli seam mine (?Tahmoor)			*																										10	20
Drill trial hole at OB prone Qld mine with structures				*																									10	20
Report on trials plus analysed data					*																								15	
Drill Fluid Logging																														
Prepare	*																												10	
Trial of system in Bulli seam low perm mine		*																											10	20
Trial of system in Qld high perm mine			*																										10	20

Task / Quarter	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	ACARP	Mine (per)
Workshop report				*																									5	
Gas Data Base																														
Expert workshop to define what data and format	*																												10	
Agreement by mines to make data available	*																													
Assembly of data from gasy mines in mine data bases		*	*	*																									75	10
Compilation of general data base or links				*																									10	
Report					*																								5	
Automated Gas Flow Monitors																														
Field test of prototype flow monitor and data links								*																					5	20
Field test link of system to CO2 mine computer									*																				10	20
Obtain commits to purchase									*																				5	
IS approval										*	*	*	*	*	*														150	
Manufacture systems for all gasy mines																*	*	*	*	*										30
Trial Borehole Pressurisation System plus Sampler																														
Mine trials with drill rig				*	*	*	*																						150	50
Report								*																						
Rotary Torque/Thrust/Survey Tool																														
Dev. prototype for UG trials	*	*																											50	
UG trials + modifications			*	*	*																								100	50
Report					*																									
Finalise design						*	*																						200	
Seek IS approvals								*	*	*	*	*	*																100	
Trial CSIRO Dielectric Tool in CO2 Mine																														
Obtain exemption approval for trial	*																													5
Trial in CO2 mine in holes with structures		*																											20	10
Report		*																											10	
Gas Pressure Gradient Measurements																														
Design trials and obtain equipment		*	*																										25	
Bulli seam in-seam tests with packers, grouted piezo			*	*	*																								25	40
Qld piezos from surface holes				*	*	*																							25	40

Quarter Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	ACARP	Mine (per)
Report intitial results and proposals for standard tests							*																						10	
OUTBURST PARAMERTERS RESEARCH																														
Rapid Gas Index																														
UG test of Polish desorbometer and EV meters													*	*															20	10
Report															*														5	
Gas Composition Change																														
Field measurements				*	*	*																							50	20
Report							*																						5	
Violence of CO2 and CH4																														
Laboratory tests	*	*	*																										100	20
Mathematical models		*	*	*																									50	
Report				*																									10	
Barrier Zones																														
Compile mine data	*	*																											25	20
Modelling		*	*																										50	
Report			*																										10	
Permeability																														
Mine UG tests in high and low perm conditions		*	*	*																									200	50
Surface tests in areas of poor drainage		*	*																										100	50
Analyse/model				*	*																								40	
Report						*																							10	
Coal Strength																														
Design trials and obtain equipment	*	*																											20	
Laboratory tests		*	*	*																									50	25
In-mine tests		*	*	*																									50	25
Analyse/model				*	*																								50	
Report						*																							10	
Stress																														
Develop method for stress	*	*																											100	

Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	ACARP	Mine (per)
testing in coal																														
Field trials			*	*																									100	50
Task																														
UG measurements in varying stress conditions				*	*	*																							75	
modelling						*	*																						25	
Report								*																					10	
Structure																														
Workshop to review known controls on OB proneness		*																											10	
Documentation of structure reln to OB		*	*																										25	
Analysis of mechanisms of struct/stress in low perm			*	*	*																								75	
Report					*																									
Training																														
Establish web site for publications	*																												40	
Establish forum with monitoring		*																											40	
Develop train the trainer course		*	*																										50	
Post graduate study encouragement	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	50	50
Establish links with European and Chines researchers		*																												
Half yearly seminars NSW and Qld		*		*		*		*		*		*		*		*		*		*		*		*		*		*	10	
Totals																													**2,925**	**725**

APPENDIX 1: BACKGROUND TO GAS CONTENT THRESHOLDS

The following notes are extracts from Lama, 1991. They relate to the Bulli Seam conditions.

p5
Certain conditions must be fulfilled before outbursts can occur. These include
The presence of a large amount of gas which also serves as a transport medium for the fractured / pulverized coal.

The presence of fractured / pulverized coal as a result of geological disturbances or as a result of high stresses and under the effects of gas.
A trigger mechanism to disturb the equilibrium as a result of mining, (breaking the barrier) or blasting.

p12
The greater the stress and the coal-gas bearing capacity and the lesser the coal strength, the greater the coal and gas outburst hazard.

Decrease in stress or geological or mining disturbance induces non- equilibrium state and the appearance of free gas filling the vacancies formed.

Disturbances of equilibrium of coal-gas solid solutions by prior cracking or fracturing of coal is therefore an essential element in outbursts.

Famin found that speed of outburst propagation increased with increase in gas pressure gradient and the size of the opening. CO_2 gave higher speeds than CH_4 and N_2.

p14
…Carbon dioxide, which is adsorbed at a late stage would result in build up of higher stresses in localised pockets and cause intensification of stresses during mining… The amount of CO_2 adsorbed is 2-3 times that of CH_4. The desorption rate of CO_2 from coal is much slower than for CH_4 (keeping in mind the total quantities of gas present).
 (seems to be inconsistent with what is in p176 and p178   Choi).
…as a result, higher gas pressure gradients can be expected in seams with high CO_2 gas levels.

p18
In general, with the two exceptions, one can conclude that there is a remarkable agreement by the various investigators on the underlying philosophy of the predictive methods and the index values. three basic points stand out:
The probability of an outburst is related to a certain critical amount of gas present in the coal seam some distance head of the face
The critical value of the outburst index is higher when CH_4 is associated with outbursts compared with CO_2
The higher the crushing of the sample (micro fractures), the higher the desorption (V or Delta P), the greater the danger of an outburst
p20
 The higher the strength of coal, the lesser the chance of an outburst, all other factors remaining constant.

p 37
Example of outburst mining at Tahmoor - outburst at plus 10 m3/T

Page 40 conclusion

For strong un-sheared coal in the absence of any structure, the gas content should be brought down below 10 cubic metres per tonne when the gas is mainly methane and below 7 cubic metres when the gas is mostly carbon dioxide.

In case of sheared coal or in the presence of a structure, the gas content for pure methane must be below 7 cubic metres and for pure carbon dioxide the gas content should be below 4 cubic metres.

The above gas contents all refer to desorbed gas, NOT to total gas.

Lama further modified the above values in his paper in the Outburst Symposium, 1995. Extracts from that paper follow.

p175
In modern theories, three factors, gas pressure gradient and gas quantity, rock pressure and strength play a dominant role.
... projection of laboratory data to conditions appearing in the Bulli seam indicates that for carbon dioxide, gas pressure of 0.35 MPa would be needed. The process of the destruction of the coal is in multiple steps producing discing as in drilling in high stress zones. The thickness of the slice is determined by the gas pressure gradient and the tensile strength of the coal, coal porosity, gas viscosity and filtration coefficient.

p176
the higher destructive effect of CO_2 is not wholly due to higher quantity of CO_2 that coal is capable of sorbing and higher rate of desorption, but also its effect on reducing the strength of coal by as much as 30%. CO_2 also has lower diffusion coefficient, higher viscosity and all this leads to higher free gas pressure gradients. At high pressures (20 - 30 atm), velocity of propagation in strong coals under high stress may reach 100 m/sec. Projection of the data to natural coal porosity levels of the Bulli seam indicates that the propagation rates would be of the order of 5 m/sec.

p177
... For an outburst to occur, there must be a large percentage of fine coal and high gas present. The larger the percentage of fine coal, the greater the severity and size of an outburst. Similarly, if high moisture is present, it will decrease desorption rate and hence the probability or the intensity of an outburst. Coal seams that have well developed micro-crack structure (lower strength) and lower permeability are thus much more liable to outbursts.

... Analysis of outbursts in the Bulli seam has shown that as long as minimum distance from the structure is maintained, an outburst will not occur... At West Cliff, this minimum distance is 2. 5 m... At Tahmoor, the width of this barrier was found to be just under 2 m.

... As the face approaches the structure and the minimum distance (thickness of barrier) is reached, the higher gas pressure displaces the material from the face and high flow rate provides the energy resulting in the initiation of an outburst.

p178
The phenomenon of discing has been observed in high CO_2 areas in the Bulli seam when coring for measurement of gas content. This occurs when gas content exceeds 16 m3/T... Discing has not been

noticed in areas with methane up to 16 m3/T. It is felt that besides high desorption rates, the affect of C02 on strength of coal plays an important role. Decrease in shear strength of coal by 30 percent has been measured under laboratory conditions.

p 184
 Data on carbon dioxide and methane from Bulli coal samples shows that the 15 second desorption rates at 4 m3 of C02 is almost equal to that of methane at 8 m3/T and C02 decreases the shear strength by 30%.

 p 185
It is now accepted that the factors that influence an outburst are
Tensile strength of coal
Gas emission rate
Gas pressure gradient
Moisture level
Depth or stress levels

If an outburst was to occur in the Bulli seam without the presence of a structure, the gas content value will have to be at least 30 m3/T of desorbable gas or 15.5 m3/T of total gas. Studies of failure of boreholes have shown that gas content is 18 m3/T (total) when outbursts in boreholes have occurred in C02 areas.

Lama and Bodziony, 1996
p 225
Ettinger, 1952 Although coal seams both liable to outburst and not liable to outburst belong to the same class of metamorphism and which have undergone the same degree of coalification, may have the same capacity to sorb gas, but they do differ in their rate of desorption. Coals liable to outbursts desorb much faster. This led to development of methods and sorption desorption indices.

According to Ettinger 1979, "owing to the predominance of bulk absorption, the CH4 - coal system is close to the concept of a methane solution, which may resemble a super-heated liquid or a super-saturated solution in a metastable state. In the case of an outburst, the system, coal seam - sorbed methane, changes from the metastable state to a stable state and is converted to an aerosol system of coal dust and free gas. The energy of the state of stress of the former system is converted to the kinetic energy of the gas. Swelling of coal can result in two independent consequences: firstly it can lead to storage of energy in the methane - coal system. Secondly it can cause the methane to go into a metastable state. In tectonicly faulted crushed coal in a state of stress, there is a possibility of rapid emission of sorbed methane during the process of stress discharge, because there must then be further cracking and crushing of the coal. If the seam contains a burst - prone zone for which the energy of swelling is especially high, sudden breakdown of the barrier of impermeable coal by mine workings or movements of the surrounding rocks can cause a catastrophic change of state of the coal - methane system, ie discharge of the sorbed methane and relaxation of the stress. For a methane - coal system in a true metastable state, the "trigger" mechanism can be almost nothing."

p 226 Kristianovich - a rapid dynamic stress relief in the crushing wave marks the total gas pressure differential concentrate in a very narrow near - face layer (discs) in coal (rock). It causes layer - by - layer breaking away, coal crushing into very fine particles with practically complete evolution of free gas out of the coal.... The crushing wave travels from the face into the solid, destroying successive layers of coal in the direction opposite to the direction of movement of broken coal mass.

... Differential gas pressure at the face of the crushing wave is at least equal to the tensile strength of coal splitting it into small layers (discs). The second source of energy is the sorbed gas that is capable of being liberated immediately within the crushing wave and later in the outburst wave. The outburst wave can develop only when the drop in pressure behind the crushing wave is sufficient to drive the crushed coal mass. This process is therefore like pushing or collapse of coal.

p 227 Shochinski, 1954 - a sudden drop of gas pressure, of the order of 2 MPa or more over a distance of 1 mm alone is enough to crush coal, throw it and ensure propagation of the crushing wave to a certain distance into the rock mass. ... The gas liberated from the fractured and crushed coal is sufficient to cause an outburst if the gas pressure is at least in the range of 0.3 to 0.6 MPa.

Page 254 swelling energy - the stress due to swelling results in storage of a large amount of energy in the gas - coal system. The liberation of this energy in the coal seam can have a decisive influence on the development of an outburst.... Swelling stress can reach levels of 270 MPa for carbon dioxide, which is far higher than any geostatic stress which is usually the range 20 - 30 MPa.

Page 256 - All tests on outbursts show the role of gas in the process of initiation and propagation and that gas pressure gradients are very important. Close to the face of a coal seam develop tensile stresses which play a dominant role in fracturing and the failure occurs by discing. Thus this process should be the basis of calculation for the surface energy of coal particles.

APPENDIX 2: *SUMMARISED RESULTS OF RESEARCH NEEDS SURVEYS*

	All respondents			Bulli seam			Queensland			Researchers		
	Fundamental Research	Develop New Tools/ Technology	Application of Technology									
OUTBURST MECHANISM												
1. Energy systems for outbursts	**2.5**	1.6	2.2	1.9	1.0	1.3	2.9	2.4	**2.6**	2.1	1.1	2.4
2. Relative roles of gas, stress, strength, strain etc	**3.5**	2.3	**3.2**	**2.9**	2.0	2.0	**3.9**	**2.9**	**3.7**	**3.3**	1.9	**3.4**
3. Modelling of outbursts	**2.6**	**2.9**	2.2	2.4	2.4	2.1	**3.3**	**2.7**	**3.0**	1.9	2.4	1.6
4. Assessment of outburst potential in various stages of mining cycle	**2.6**	**2.8**	**2.5**	2.1	**2.8**	**2.5**	**3.6**	**2.9**	**3.0**	1.9	1.8	1.8
ASSESSMENT OF OUTBURST POTENTIAL												
5. During exploration	**3.3**	**2.7**	**2.6**	**2.8**	**2.5**	2.1	**4.0**	**3.3**	**3.7**	**2.5**	2.1	2.1
6. During initial excavation	2.3	2.4	**2.6**	0.9	1.3	1.9	**3.7**	**3.4**	**3.7**	1.8	2.1	**2.5**
7. During mining development	**2.5**	**2.8**	**3.0**	1.3	1.8	2.4	**4.0**	**3.6**	**3.9**	2.0	2.1	**2.9**
8. During longwall mining	1.8	2.2	2.4	1.0	1.3	1.9	**2.9**	**2.6**	**2.9**	1.5	1.9	**2.5**
ROLE OF GAS												
9. Gas content measurement methods (AS3980 - Approved quick method)	1.9	**2.5**	2.3	1.5	**2.5**	2.1	2.4	**2.6**	**2.9**	1.6	2.1	2.1
10. Gas index methods (rapid testing)	2.0	**2.8**	2.0	1.5	1.9	2.0	2.4	**2.6**	**2.9**	1.5	**2.9**	1.9
11. Gas pressure testing post drilling	1.8	2.2	2.0	1.4	1.8	1.8	2.1	2.3	**2.6**	1.5	2.4	1.8
12. Gas pressure determination during drilling	1.9	2.3	1.8	1.5	1.6	1.6	2.1	2.3	**2.6**	1.8	2.1	1.6
13. Scientific basis/validation of outburst indicator thresholds	**3.3**	**2.6**	**3.3**	**3.3**	1.9	2.0	**3.3**	**3.6**	**3.7**	3.1	2.1	**3.9**
14. Roles of mixed gases in outburst potential	**2.7**	2.3	**3.1**	2.4	2.4	2.3	**2.7**	**2.7**	**2.7**	**3.0**	1.6	**3.8**
15. Role of permeability changes in outburst potential	**3.3**	**2.5**	**3.4**	**3.3**	2.5	2.3	**3.6**	**3.3**	**3.3**	2.9	1.4	**3.9**
16. Measurement of gas make from holes during drilling (outburst prediction)	2.4	**2.9**	**3.1**	2.1	**2.5**	2.4	**3.0**	**3.7**	**3.6**	1.8	2.3	**2.8**
17. Measurement of gas make from holes during drainage (gas management)	2.2	**3.0**	2.4	1.3	**2.9**	1.9	**2.9**	**3.1**	**3.4**	1.5	**2.9**	**2.6**
18. Gas reservoir modelling	**2.5**	**2.8**	**2.7**	**2.8**	2.1	1.8	**2.7**	**3.1**	**3.1**	2.1	**2.6**	**2.8**
19. Methods to reduce the risk associated with gas content sample spacing	**2.5**	2.4	2.3	**2.5**	1.4	1.6	**2.9**	**3.1**	**3.4**	2.1	**2.5**	1.8
20. Gas sources/provenance	2.0	1.5	1.9	2.1	1.5	1.5	2.0	1.9	2.4	1.8	1.0	2.1
21. Real time monitoring of airway gas to indicate outburst potential	1.8	2.1	2.0	1.8	1.5	2.1	2.1	2.1	**2.6**	1.5	1.5	1.4
22. Gas composition change with drainage as O/B proneness index	**2.7**	**2.5**	2.2	**3.0**	2.4	2.0	**3.0**	**2.9**	**2.7**	2.0	2.0	1.5
GEOLOGICAL STRUCTURE												
23. Differentiation between prone and non-prone structures	**3.5**	**3.1**	**2.8**	**3.1**	2.4	2.4	**4.3**	**3.1**	**3.4**	2.9	**3.1**	**2.5**
24. Remote detection (non-drilling) structures	**2.9**	**3.0**	**3.0**	**3.0**	**3.0**	2.8	**3.3**	**4.0**	**4.4**	1.6	2.0	2.3
25. Statistical modelling of geological structures	1.8	1.9	2.2	1.8	2.0	1.4	2.0	2.0	2.4	1.4	1.1	2.4

26. Mapping/presentation techniques to improve reliability of proneness prediction	2.0	**2.5**	1.9	2.0	2.4	1.4	1.9	**2.6**	2.1	1.5	2.3	2.4

COAL PARAMETERS

27. Relationships between Rank, Moisture, VM, etc to outburst proneness	2.2	2.0	2.2	**2.6**	1.8	1.8	**3.0**	2.9	2.9	1.5	1.4	1.5
28. Relationships between macerals (coal make-up) to outburst proneness	**2.5**	2.3	2.4	**2.9**	1.8	2.0	**3.3**	**3.0**	2.9	1.9	2.0	1.8
29. Effects of cleat filling on drainability	**3.0**	**3.1**	2.7	**3.1**	**3.0**	2.6	**3.3**	**3.4**	**3.4**	1.9	2.3	**2.9**

DRILLING, LOGGING AND DRAINAGE

30. Detection of outburst prone structures in in-seam boreholes	**3.0**	**3.6**	**3.0**	1.9	**3.5**	2.8	**3.3**	**3.6**	**4.4**	**3.0**	**3.0**	2.9
31. Borehole stability during drilling	2.3	**2.5**	**2.5**	2.0	1.9	1.6	**2.7**	**2.6**	**2.9**	1.8	2.3	**3.4**
32. Target drilling for long holes	1.9	**2.5**	2.3	1.0	1.9	1.8	**3.0**	**3.0**	**3.7**	1.4	1.8	2.0
33. Straighter rotary drilling	1.8	2.3	1.8	0.9	1.5	1.6	**2.6**	2.4	2.4	1.5	2.0	2.0
34. Rotatory hole survey tool for use during drilling	2.1	**3.0**	2.3	1.3	2.1	1.9	**3.0**	**3.4**	**3.6**	1.4	**2.8**	2.1
35. Accuracy of borehole surveying	1.9	**2.7**	**2.6**	1.1	1.9	2.3	**2.7**	**3.4**	**3.7**	1.5	2.4	2.4
36. Flow monitoring of drainage holes for efficiency	2.0	**2.9**	**2.5**	1.0	**2.6**	2.8	**2.7**	**3.0**	**3.1**	1.4	**2.6**	2.4
37. Reduction of drilling and drainage costs	1.8	**2.7**	**2.6**	1.5	1.9	2.6	**2.9**	**3.3**	**4.0**	0.6	1.9	2.3
38. Recovery of undesorbed cuttings for gas content	1.8	2.4	**2.8**	1.5	1.9	1.9	**2.7**	**3.1**	**3.4**	1.3	1.9	**3.1**

SAFE MINING TECHNOLOGIES

39. Remotely controlled equipment	2.3	**2.5**	**2.8**	1.4	2.3	2.3	**2.7**	2.4	**3.0**	2.3	**2.6**	**2.9**
40. Ventilation practices to reduce risk	1.7	2.0	1.8	0.6	1.1	1.1	**2.7**	**2.6**	**3.0**	1.4	1.6	1.8
41. Protection of operators	2.3	**2.7**	2.4	1.6	2.0	2.3	**2.9**	**3.4**	**4.0**	1.8	1.8	2.0
42. Training of operators in outburst awareness and procedures	1.9	**2.5**	**2.6**	1.4	1.5	2.1	2.3	2.4	**3.3**	1.6	2.4	**3.1**
43. Risk analysis of current mining methods and practices	1.8	2.1	2.3	1.0	1.0	1.8	2.3	2.4	**3.0**	1.6	2.1	2.3
44. Reduced risk mining methods	**2.5**	**3.0**	2.4	2.0	**2.5**	2.8	**2.9**	**3.0**	**3.3**	1.5	**3.0**	2.0

REMOTE SENSING AND FACE MONITORING

45. Microseismics for outburst prediction	**2.8**	2.4	**2.9**	**2.5**	1.8	1.5	**3.1**	**3.3**	**3.4**	2.3	2.1	**3.4**
46. Face scanner for prediction of outbursts	2.4	2.2	2.3	**2.6**	1.9	1.6	2.4	**2.7**	**2.7**	1.5	1.9	1.9

COMMUNICATION/EDUCATION

47. Development of a web site for gas/outburst references	1.8	2.2	**2.8**	1.4	0.9	1.9	**2.7**	**3.4**	**4.1**	1.3	1.9	2.3
48. Development of a web site for a gas/outburst forum	1.5	2.1	**2.5**	1.4	0.9	2.0	2.3	**3.0**	**3.3**	0.8	2.0	2.3
49. Regular (half yearly) gas/outburst seminars	1.5	**3.1**	2.9	1.0	1.8	2.8	**2.9**	**3.6**	**3.7**	0.5	**2.9**	2.8
50. Central register of outburst related occurrences	1.7	**2.6**	**3.0**	1.0	1.8	2.0	**3.1**	**3.3**	**4.1**	0.8	2.4	**3.0**