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HISTORY OF OUTBURSTS IN AUSTRALIA AND CURRENT MANAGEMENT CONTROLS

Chris Harvey[1]

ABSTRACT: Outbursts have been recognized as an inherent, world wide mining related phenomenon since the 1850's. The level of understanding has grown and developed as Mining Engineers and Geologists have been able to gain more understanding of coal seam characteristics and measure or test various coal or seam parameters such as seam gas content, seam gas pressure, coal strength and depth of cover. This paper outlines some of the concepts associated with understanding the factors, which contribute to outbursts and details more specifically the nature of outbursts experienced in Australia, especially for the Bulli Coal Seam. A number of key outburst incidents, which have had a distinct bearing on outbursts management concepts, are considered along with the current outburst management approach.

INTRODUCTION

The identification of the specific set of circumstances attributed to "outbursts" is believed to have followed from the observations of Taylor (1852-53). This study based upon experience in British mines identified three types of gas emissions, the first form of gas emission being characterized as the free gas, which is emitted from the coal to atmosphere and is in equilibrium with the atmosphere. The second form of gas emission was identified as being associated with highly compressible gas being present within the coal at high pressure. A particular characteristic of this gas emission is its slow release through the natural structure and pathways within the coal, creating the cracking, dislodgement and "bursting" of small pieces of coal as the gas is emitted. The third form of gas emission was identified as a variation of the second form and was associated with changes in the coal structure, which have disturbed or stopped the flow of the higher compressible gas. It was identified that the presence of faults and basalt intrusions caused the gas or the migration of gas through the coal seam to become irregular or non-uniform, resulting in "gas pockets" in certain areas. Taylor postulated that the mining of these areas would subsequently result in sudden emissions of gas and its sudden dispersion into the mine workings. Hence an early and accurate definition of outbursts was developed, which identified the role of geological structures, folds and dykes, changes in structure of the coal and the existence of high gas pressure.

The interaction of seam gas, (gas content in m^3/tonne) and gas pressure, in combination with tectonic characteristics such as seam structures, dykes and faults has been identified as determining the outburst potential. Nekrashovski (1951) identified possibly for the first time that outbursts are not the result of a single factor but rather a multiplicity of factors acting together. It was identified that gravity has a role to play particularly for steeply dipping seams where the potential for outbursts to be initiated in roadways driven to the rise, is greater than for roadways driven to the dip.

CURRENT OUTBURST CONCEPTS

In general terms, it is universally recognized that an outburst is the sudden release of a large quantity of gas in conjunction with the ejection of coal and associated rock, into the working face or mine workings. The violent and unexpected nature of these events enhanced the risk and danger to mine workers. It is also recognized that numerous factors can contribute to the specific nature or characteristics associated with outbursts in a particular coalfield with the three primary factors being:

- Intense stress within the coal seam
- High gas content and high gas desorbability
- Low coal strength

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Following from this and work by prominent industry researchers in Australia such as Alan Hargraves and Ripu Lama, the current information and understanding of outbursts has tended to involve the following factors.

- An inherently high in situ gas content for the coal seam associated with a rapid rate of desorption and greater depth of cover.
- Geological structures have a major link with the incidence of outbursts particularly strike slip faults.
- Compression type structures, such as reverse or thrust faults and strike slip faults have a greater potential to create mylonite, sheared and crushed coal than tensional structures such as normal faults.
- Mylonite and crushed coal has the potential to desorb very rapidly and when combined with localised stress conditions, which greatly reduce permeability, there is the potential for pockets of pressurised gas to be associated with structures.

This tends to reflect the general belief and assumption, based upon previous outburst incidents, that Bulli seam outbursts are largely considered to be a gas-dynamic phenomenon, rather than geo-dynamic. The necessary high strata stress component is related to geological anomalies rather than being a normal in situ seam condition induced by depth of burial, high lateral stress and mining induced stress. The latter being of particular note for outburst incidents at Leichhardt Colliery in Queensland. Hence any outbursts management strategy must reflect the multiplicity of facets or components, which characterise outbursts.

AUSTRALIAN EXPERIENCE

Outbursts have occurred in the Sydney Basin, Illawarra Coalfield and the Bowen Basin, Northern and Central Queensland. These two Basins are linked geologically and cover an area of 220,000 km^2, but have been defined separately upon regional and or local characteristics. Over 700 outbursts have been recorded within Australia over 106 years.

The Bulli Coal Seam, located within the Illawarra Coalfield to the south of Sydney, has the dubious honour of having the first recorded outburst in Australia at Metropolitan Colliery on September 1895. The various characteristics and peculiarities of Bulli seam outbursts are discussed in more detail below.

With regard to the Bowen Basin in Queensland, three collieries have experienced outburst incidents, these being mines in the Collinsville area along with Leichhardt and Moura Collieries. Both methane and carbon dioxide outbursts have been recorded with the primary characteristics being the presence of geological structures and a higher level of in situ seam gas. The physiological effects and characteristics associated with carbon dioxide have received particular attention especially in reviewing outburst related fatalities.

Queensland Outbursts

Outbursts in the Collinsville Area
Instantaneous outbursts in the Collinsville area were referenced by Hargraves (1958) and most recently by Lama and Bodziony, (1996). The seam outcrops on the northern rim of the Bowen Basin and has been subjected to various levels of deformation as identified in the nature and frequency of faulting, the rank of the coal and the wide spread occurrence of igneous intrusions. Low reverse angle thrust faults, in conjunction with bedding plane and slip strike faults are common. The Western extent of mining within the No.2 State Mine was limited or controlled by the Three Mile Creek Fault, which is a thrust fault with 400 metres of throw.

The first outburst incident for the Collinsville area occurred at the State Mine in 1954 at a depth of 250 metres. It resulted in the death of seven men and three horses, with carbon dioxide being the prominent gas. A royal Commission was held in 1956 following these fatalities. Since 1954 there have been nineteen outburst incidents recorded for the Collinsville area as documented by Williams and Rogis (1980). It would appear that as mining operations developed within the Collinsville area and it became more difficult to manage or control the outbursts, the mines were closed and re-started at shallower depths, near the outcrop. Consequently four separate mining operations have been undertaken in the Bowen coal seam, over a 50 year period, with operations being closed or restarting at shallower cover as the depth of workings approached the critical depth, ranging from 250 metres to 280 metres.

Outbursts at Leichhardt Colliery

Leichhardt Colliery is located within the Bowen Basin, to the South of the central Queensland town of Blackwater. As described by Hanes (1995) and Lama and Bodziony (1996), the colliery reported its first outburst incident in 1974 while mining the Gemini coal seam at an overall seam thickness of 6 metres (with an average working or extraction thickness of 2.5 to 2.8 metres) and depth of cover ranging from 350 metres to 410 metres. The local geology at the mine was regarded as structurally complex due to a number of faults of less than 10 metres throw, striking to the North West. The colliery workings were intersected by three prominent faults, two being steeply dipping normal faults of throw greater than 10 metres and the third being a shallow dipping reverse fault of 3.5 metres throws. Gas content of the Gemini coal seam was measured at 16 m^3/tonne, being predominantly CH_4.

The outburst in 1974 occurred when mine workings had only developed 175 metres from the seam inset of the No. 2 shaft. In all, more than 200 outburst incidents were recorded at Leichhardt Colliery with three dislodging 300 tonnes or more of material. The largest outburst occurred on the shallow dipping reverse fault with minor displacement (~200 mm). The outburst which was associated with sheared and brecciated coal in the vicinity of the fault, ejected 500 tonnes of coal and approximately the same amount of rock.

Coal mining operations were undertaken using either a Joy 10CM or a Voest Alpine road header (used to cut a profiled roadway) until 1978 when following a major outburst, shot-firing was used. It was believed that outbursts at Leichhardt Colliery were stress controlled and gas induced. This was further complicated by mining induced cleavage and stress within the coal, which when combined with a directional permeability tended to create a higher than normal gas pressure gradient, based primarily upon the direction and orientation of the mine workings. The interplay between horizontal stress, (identified as being the maximum principal stress), vertical stress and mining induced stress was best described by Hanes (1995). The nature of mining conditions, gas content and ultimately the inability to successfully manage or control outbursts, all contributed to the mine being closed in 1982.

Outbursts at Moura Colliery
Moura No. 4 Colliery was an underground mine developed off the high wall of an open cut. The seam being mined had a total height of 5.2 m with the lower 2.5 metres being mined and a shale/sooty coal band, reported to be mylonitised coal, in the roof. Gas content for the seam was measured at between 8–9 m^3/tonne with a maximum seam gas pressure of 1.03 Mpa (gauge) for a vertical depth of 135 metres (Troung et al, 1983).

Three outbursts have been recorded for Moura No. 4 Colliery with two of the three incidents being related to a major joint zone. The third outburst was believed to be associated with a zone of weak coal, uncharacteristic of normal condition in the mine. Generally outbursts were not considered to be a significant mining related problem due to the high strength of the coal, the low seam gas content and the slow desorption rate. In 1995 the mine was closed following a methane gas explosion, which resulted in nine fatalities.

Bulli Seam Outbursts

The first reported outburst incident in the Illawarra Coalfield occurred on 30 September 1895, according to Hargraves (1965). Details as to the size and intensity of this and other early incidents are very sketchy, however it would appear that all the early incidents (1895 to 1911) were associated with faults, dykes or zones of fractured coal, the discharge of both CO_2 and CH_4.

Table 1 gives an indication as to the number of outburst incidents attributed to each mine working the Bulli Coal Seam and the next section, provides some insight into specific details of outburst incidents, for particular mines. The outburst phenomenon was not treated with the same degree of importance as that exhibited in some coalfields throughout Europe and elsewhere in the world, due primarily to the comparative low fatality rate. To date there have been twelve outburst related fatalities for the Bulli seam and these have predominantly been associated with carbon dioxide, and seam structures

Table 1 Bulli Seam Outbursts

Colliery	No. of Outbursts	Size in tonnes	Gas	Geological Structure
Appin	26	2 - 88	mainly CH_4, with CO_2 on dykes.	Predominantly strike slip faults; mylonite zones.
Brimstone (closed)	2	30	CO_2	Mainly dyke related structures with strike slip movement.
Corrimal (closed)	4	12	CH_4 & CO_2	Shear zone associated with minor faulting & dykes.
Kemira (closed)	2	60 - 100	CO_2	normal fault with mylonite.
Metropolitan	154	Up to 250	mainly CO_2 with minor amounts of CH_4	Predominantly with dykes & faults that exhibit slicken sides & mylonite.
Bellambi West (South Bulli)	13	1 - 300	mainly CO_2	Strike slip faults with mylonite; dyke zones & thrust faults.
Tahmoor	90	5 - 400	mainly CO_2	Mainly strike slip faults; with dykes (110^o - 135^o) & thrust faults: mylonite usually present.
Tower	19	1 - 80	mainly CH_4	Mainly strike slip faults with dykes.
West Cliff	254	4 - 320	mainly CH_4 with CO_2 to the NE development	Predominantly strike slip faults (100^o - 110^o) with slicken sides & mylonite; dykes and thrust faults have been associated with outbursts.

Mine by Mine Experiences

Appin Colliery
Appin Colliery has recorded 26 outbursts varying in size from less than 2 tonnes through to a reported 88 tonnes. The first outburst occurred in May 1966. It ejected 50 tonnes of coal along with an unknown but significant amount of CH_4 and was related to a zone of joints that were evident in the immediate roof. Five small outbursts mainly less than 8 tonne but one up to 20 tonne have occurred with no prominent geological structure. Strike slip faults tend to account for the majority of the outbursts along with one occurring adjacent to a dyke and associated with cindered coal. The largest recorded outburst occurred in July 1969, ejecting 88 tonnes of coal and a large amount of CH_4. Some 2 hours after the event 4% CH_4 was measured in the general body. This outburst was associated with a strike slip fault and a readily identifiable mylonite zone 0.05 metres wide.

Gas content at Appin is in the order of 13 m^3/tonne and an extensive gas drainage system is used to prevent or minimise the risk of outbursts and manage gas liberated during mining. Composition of the gas is predominantly CH_4, however high CO_2 has been recorded adjacent to faults and dykes.

Corrimal Colliery
Corrimal Colliery, now part of Cordeaux Colliery, recorded four outbursts associated with a north easterly trending shear zone, minor faulting and dykes. The first outburst occurred in October 1967, ejecting 5 tonnes of coal and an unknown amount of gas. It was associated with a shear zone exhibiting strike slip faulting, crushed coal and mylonite as well as two thin dykes, less than 1m in thickness. The largest outburst occurred in November 1967 discharging up to 12 tonnes of coal with both methane and carbon dioxide in unknown quantities being given off. All the Corrimal outbursts were associated with a shear zone that bisected the colliery with outbursts being reported in the central and southern extent of the zone. The outburst prone areas were related to intense jointing with mylonite being present in lateral bands and within the cleat near the roof. This shear zone is a prominent geological structure and is recognisable on aerial photographs.

Kemira Colliery
Kemira Colliery, now closed, recorded two outbursts in May 1980 and May 1981 on a single normal fault of 0.4 to 0.7 metres vertical displacement. Mylonite was identified in bands and within the cleats near the roof at the outburst sites. Carbon dioxide was the predominant gas with 60 and 100 tonnes of coal being discharged.

Bellambi West Colliery
Bellambi West Colliery, formerly known as South Bulli Colliery, had its first outburst on a 110° "shear zone", located in the northern part of the mine. A small hole or cone near the roof was associated with the outburst. Further small outbursts have occurred along the same shear zone with 5-30 cm of mylonite being identified. Also in the northern part of the mine the dip of the seam changes from 1° to 10° with accompanying bedding plane shears in a claystone band located 10-15 cm from the roof. This acts as a preferred shear band and as many of the outbursts occurred at this level the sheared claystone area was regarded as having outburst potential. In the southern part of the mine an outburst occurred associated with a dyke zone. This had a breccia pipe inside the dyke zone and cindered coal. Significant quantities of carbon dioxide were liberated.

The fatal outburst at South Bulli Colliery on 25 July 1991 was also the largest recorded for the colliery and related to a low angle thrust fault with a 35 cm band of powdered coal. Approximately 2 metres of the face collapsed with the outburst and a cavity was formed in the right hand side of the face resulting in 300 tonne of coal being discharged. The gas liberated was predominantly CO_2 with high gas pressures being noted from drill holes used to prove the fault after the outburst incident.

Metropolitan Colliery
This mine has the longest history of outbursts in the Bulli Seam. Going back to 1895, it has recorded a total of 154 outburst incidents and has been associated with the greatest number of outburst related fatalities, (seven lives lost). A review of relevant reports and information indicates that the majority of the outbursts occurred on structures, especially a zone known at the mine as the "soft outburst zone". Gas composition and gas content varies greatly throughout the mine, with the presence of faults and dykes being considered the primary cause.

Work undertaken by Hargraves (1965) showed a correlation between mining method, advance rate and outbursts. Inducer shot firing was used at Metropolitan Colliery as a means of initiating outbursts. The largest recorded outburst ejected 250 tonnes of coal and was induced by shot firing. Between 1961 and 1968 some 100 outburst incidents were believed to be related to inducer shot firing.

Zones of outburst potential can be plotted on the colliery plan based upon previous experience. With the last fatal outburst at Metropolitan being in 1954 it could be argued that management of the outburst risk was satisfactory. However, the most recent outburst in September 1992 had the potential to endanger mineworkers especially as the various warning signs while being clearly evident were not recognised by workers and supervisors.

Tahmoor Colliery
Tahmoor Colliery has had 90 outbursts since 1981 with the majority of them being associated with east south easterly structures, mainly dykes and strike-slip faults, with an orientation of 110° to 135°. It is believed that the dykes have been reworked with strike slip fault movement. A series of north easterly reverse faults have been associated with four outburst incidents and these structures have been difficult to drill by conventional rotary methods. The following is a summary of outbursts at Tahmoor:

Table 2 Outburst Summary for Tahmoor Colliery

Structure	***N° of Outbursts***	***Violent***	***Size (tonne discharged)***
Across Dyke	3	3	5-400
Strike slip/dyke	28	17	5-120
Strike slip fault	55	18	5-100
Reverse fault	4	1	5-40

The largest outburst incident at Tahmoor colliery occurred in June 1985, ejecting 400 tonnes of coal and an estimated 4,500 m^3 of CO_2 into the development heading, burying both the continuous mining machine and the shuttle car. In recent times gas drainage has been used and where gas content cannot be reduced quickly enough shot firing is the preferred approach.

Tower Colliery
Tower Colliery has recorded 19 outbursts, with the first incident occurring in July 1981 and so far this has also been the largest outburst. The size of outbursts has varied from less than 1 tonne to 80 tonne with unknown amounts of CH_4 being liberated. These have predominantly occurred in the south western part of the mine, against a dyke with associated strike slip faulting. Low intensity bumping and slumping has been experienced with outburst type conditions where seam gas content of 10-12 m^3/ tonne was recorded with gas composition being predominantly methane. A gas drainage system is currently utilised to reduce the in seam gas content and control gas during mining operations.

West Cliff Colliery
West Cliff Colliery had its first outburst in December 1976 and since that time 252 outburst incidents have been recorded. This first incident ejected 120 tonnes of coal and was related to a shear zone, with strike slip faulting and mylonite and this zone proved to be the site and focus for a number of subsequent outbursts. The size of the outbursts has varied form 4 tonnes to over 320 tonnes with the majority being related to zones of strike slip faulting having a strike approximately 100°-110°. The largest outburst, some 320 tonne of coal occurred at the northwest end of a normal fault where the gas drainage holes had not penetrated. There was a major joint zone 3-4 m wide in the roof associated with this outburst site and a mylonite band some 30 mm thick.

The gas composition has been predominantly methane but several outburst events in the north eastern part of the mine have involved very high levels of gas (>16m^3/tonne) and >95% CO_2. Mining operations at this colliery have only been possible through the use of gas drainage and specified outburst mining procedures and a purpose built continuous mining machine to afford protection to the miner driver. This has minimised the risk of injury to the mineworkers and permitted mine development through many outburst zones.

West Cliff Colliery has the dubious distinction of recording the only outburst so far to have occurred on a retreating longwall face within the Illawarra coalfield. On 3rd of April 1998 two outburst incidents of low intensity occurred on the longwall face 23. The area where this occurred had not been adequately covered by gas drainage as the take off point for the face had been relocated to give an additional 45 metres of longwall coal. The outbursts were identified by 2 cavities or cones in the face at the roof extending about 1 metre into the coal. Gas samples taken after the incident but in close proximity recorded 98% CO_2 at a seam gas content of up to 21 m^3/tonne. There was no apparent structure at the face and it was believed that the outburst occurred due to the high gas content, the localised stress conditions (including mining induced stress) and the extremely low permeability of the coal (Piper, 1998; Walsh, 1999). The West Cliff Outburst Management Plan has since been amended to ensure that all longwall panels are effectively pre-drained.

CONTROL AND MANAGEMENT OF OUTBURSTS

Early Concepts

Initially outbursts were considered just one of a number of factors or problematic conditions inherently related to mining coal at greater depth. The unexpected nature of outbursts was of concern and while the maintenance of boreholes in advance of the face was considered to be desirable, the primary and most effective early method of controlling outbursts proved to be inducer shot firing. In support of this type of approach special shot-firing controls or more appropriately regulations were established, especially following on from the outburst incidents experienced at Metropolitan Colliery and at Collinsville. To some degree the major benefit of this approach was to remove people form the immediate face area, limit the number of holes to be fired at any one time, limiting the detonator delay and stipulating a minimum level of ventilation.

As mining technologies changed the concept of predicting outbursts via advanced drilling, plotting geological structures and monitoring seismic activity were developed. These approaches related to recording or assessing one particular outburst component as an indicator followed by the timely removal of workmen to limit danger. Following from this approach was the provision of purpose built mining machinery to afford protection to the continuous miner driver. While certain aspects of these types of outburst control may still be evident in current day outburst management plans they generally have a different focus and are not the only control mechanism utilized at the mine.

Outburst Management

Outburst management differs from outburst control in that management relates to managing the outburst risk. This risk management approach will utilize outburst prediction and prevention techniques with the ultimate "fall back" being the protection of mine workers, from the consequence of outburst incidents. As such, it has a human focus rather than technological and would therefore involve procedures and processes all aimed at and achieving the management aim. The inter-relationship of outburst prediction, prevention and protection is explained diagrammatically in Figure 1. This type of approach was first brought to the notice of mines operating in the Bulli coal seam after the triple fatality at South Bulli coal mine in July 1991. It involved the concept that the management of risk associated with outbursts requires the establishment and maintenance of specific "barriers" (as identified in an Energy/Barrier Chart), which prevents the "energy" from being released into the mine environment by an outburst, and endangering mine workers.

In more general terms, it was identified that there was no one specific technology or mining technique, which could be used to guarantee safety in outburst prone mines. The effective management of outbursts to ensure safe working conditions, involved a number of techniques and technologies. These technologies including measurement of seam gas content and composition, identification of geological structures, use of gas drainage techniques, identifying in situ and mining-induced stress regimes when put together in a particular format or management system could effectively manage the outburst risk. The background concepts of management systems and more specifically, quality management concepts were fundamental to the development of outburst management plans

Outburst Management Plans

The various characteristics, which lead to identifying the outburst potential, and subsequently to the outburst risk, have clearly been shown as site specific. Geological conditions and the mining methods utilised at any one particular mine site will necessitate the development of a specialised outburst management plan for that mine. This will not only reflect the techniques and technologies used at that mine to manage the outburst risk, but must reflect the "culture" at that mine, the way work is performed and the way mine management relates and interacts with the workforce. In this regard the human and organisational aspects of the plan can be considered as equal in importance to the technologies utilised, as the acceptance of an outburst management plan and its implementation is just as important as any other aspect of outburst prevention.

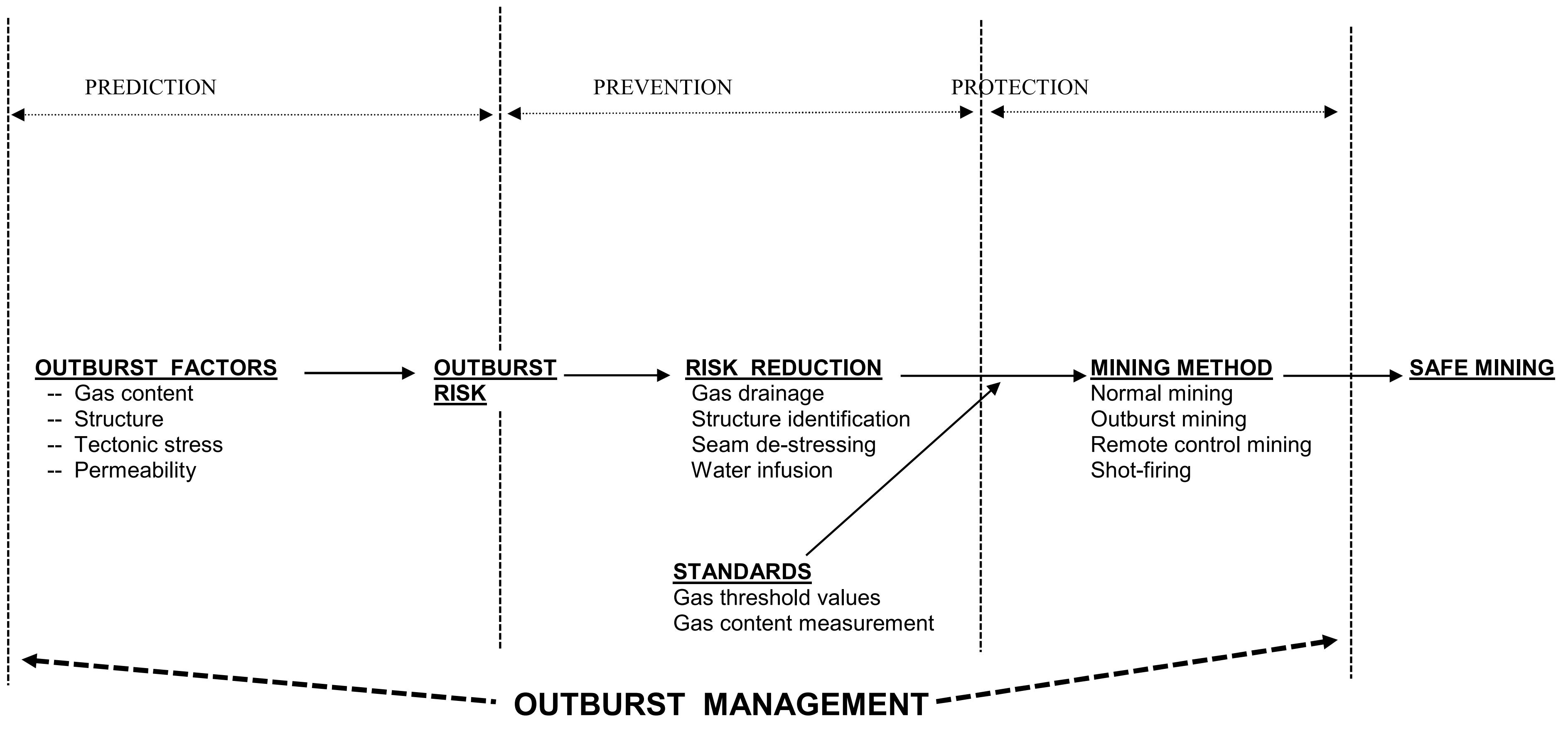

Fig. 1 Diagrammatic Representation Of Outburst Management

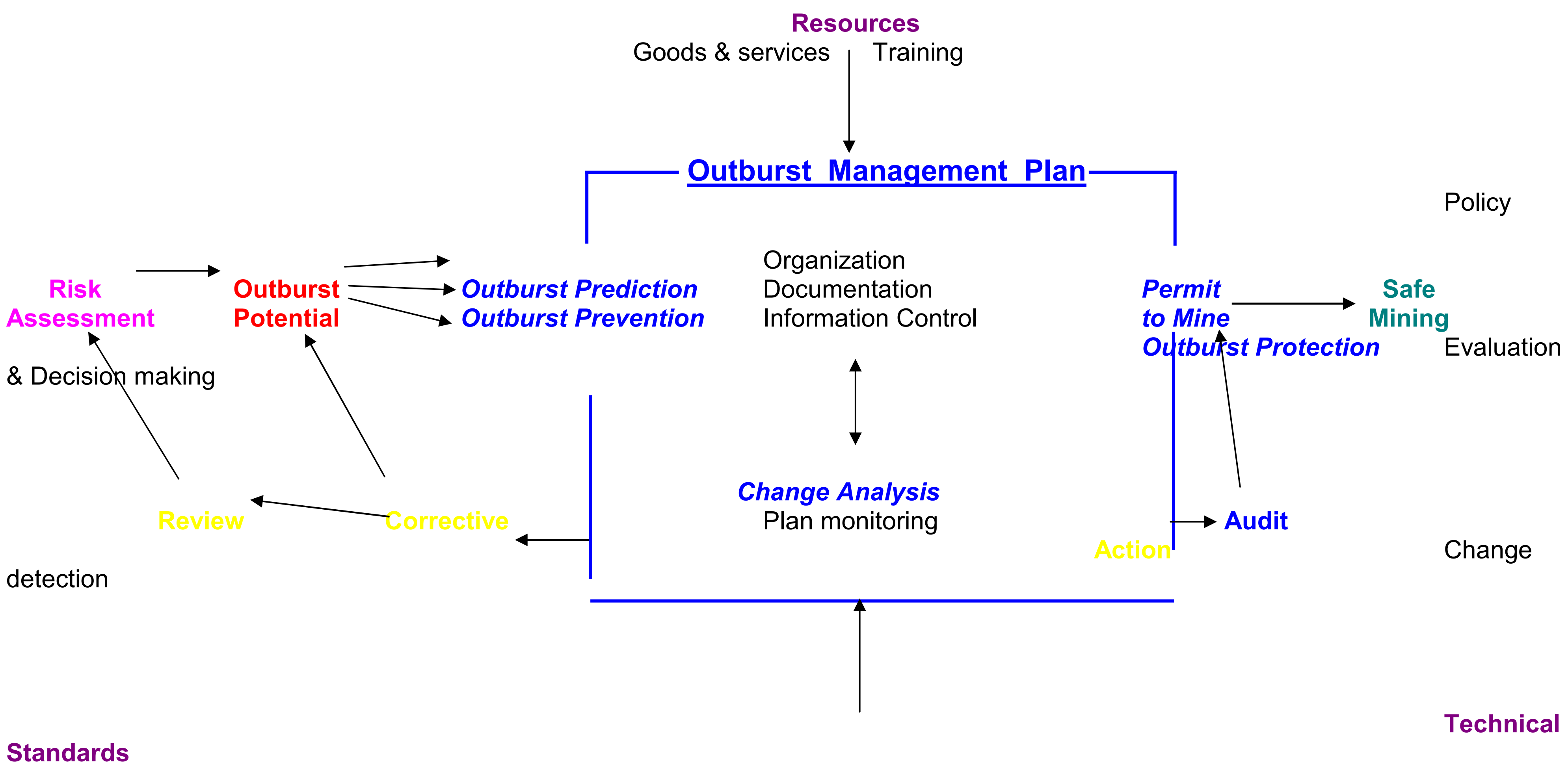

Fig. 2 Outburst Management Plans as a Safety Management System

While it is of primary importance that any outburst management plan is developed for each specific site with due regard for geological and mining conditions, for the plan to be considered as acceptable it must have a number of key elements. These elements are contained within guidance documentation as provided by the Department of Mineral Resources, Coal Mining Inspectorate, MDG 1004 (DMR, 1995). The manner in which the key components of an Outburst Management Plan fit within a Safety Management System is shown in Figure 2. This also shows how the General Requirements, Mandatory Elements and Process Requirements for each management plan inter-relate to ensure a safe mining outcome. The inclusion of the Corrective Action, Review and Audit processes are fundamental to the plan achieving its purpose and being successfully implemented.

In conjunction with the development of outburst management plans has been the enforcement via regulation, of gas threshold levels for all Bulli seam mines. While this has supported a systematic approach to reviewing outburst factors and assessing the outburst potential via the measurement of gas content, the most significant development has been the wide spread adoption of gas drainage to manage gas within the mining environment. There have been a number of additional "spin offs" resulting from this approach along with the attitude of that outburst mining is not an option and normal mining procedures will only be used.

The success of the Management Plan approach in combination with gas threshold values for Bulli seam operations is clearly exemplified in Fig. 3. This shows the major reduction in outburst incidents for the Bulli seam since the management mechanism was established for outbursts.

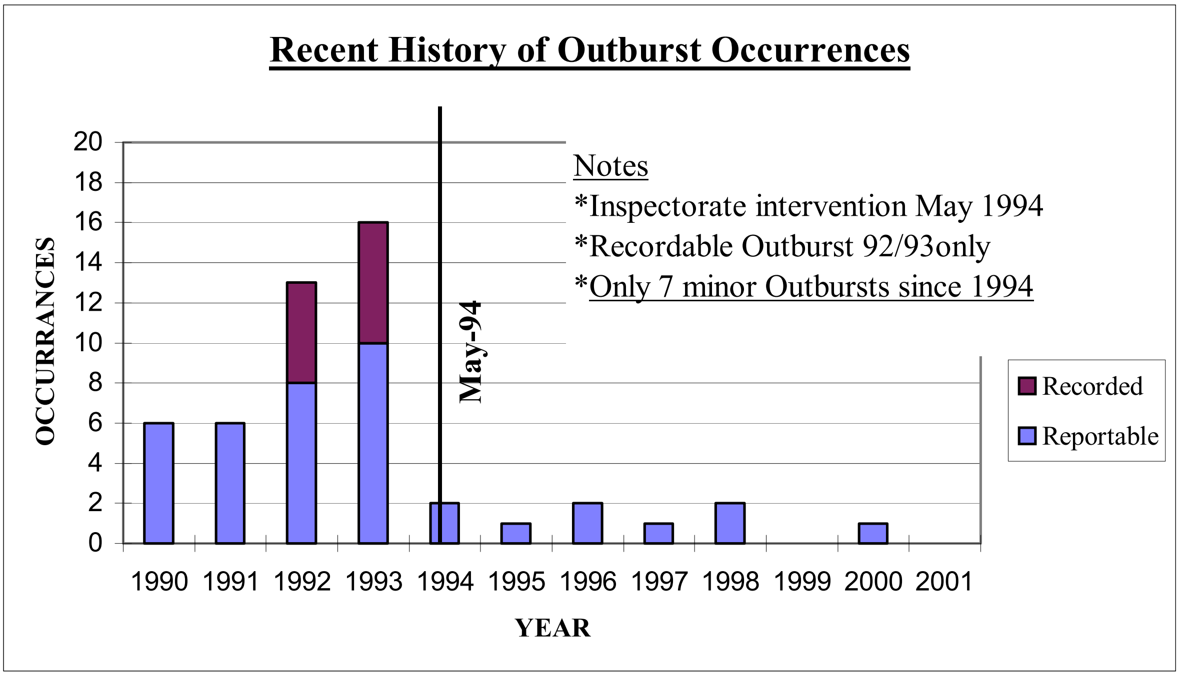

Fig. 3 Recorded Outburst Incidents Since 1990

CONCLUSIONS

It is a sad but understandable fact that the study and analysis of outburst events and characteristics has been directly related to outburst fatalities, especially multiple fatality incidents. Outbursts are a multi faceted mining phenomena and there is no single universal predictive tool. Similarly there is no one mechanism for the prevention of outbursts. Gas drainage has been the most successful outburst prevention technique, especially for the Bulli seam; though this is not universally the case and most probably would not have been of assistance in the case of coal with very low permeability (such as at Mt. Davy, NZ) and high in-situ stress.

The current approach, which utilizes management plans and directed gas threshold values, has greatly reduced the number of outburst incidents. The key benefits being the collection of data such as seam geology, gas content, gas composition, potential geological structures, lead time for gas drainage and correlation against gas threshold values. All these components are successfully combined to give a total image/picture of the coal seam immediately before it is mined. The most suitable mining method is then selected in the interests of safety and the mine manager or appropriate senior mining official then signs off on the collected information and the mining method. However ongoing training in outburst awareness must continue to be the ultimate and fundamental protection for all face workers. The ability to identify key outburst warning signs and related changes in mining conditions can save lives.

It would appear that over and above the effectiveness of the current outburst management plans for Bulli seam mines, there is an undue reliance on one outburst indicator, namely seam gas content, as the primary standard or determinant for outburst risk. For the plans to become more adaptive and comprehensive, other factors, such as seam gas pressure, coal strength and permeability, need to be considered and incorporated within the outburst management plans. This reflects the overall belief and assumption that outbursts in the Bulli seam are largely a "gas-dynamic" phenomenon and as such, this does not easily accommodate variations within the seam and the mining environment that could cause Bulli seam outbursts to become "geo-dynamic" phenomena.

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