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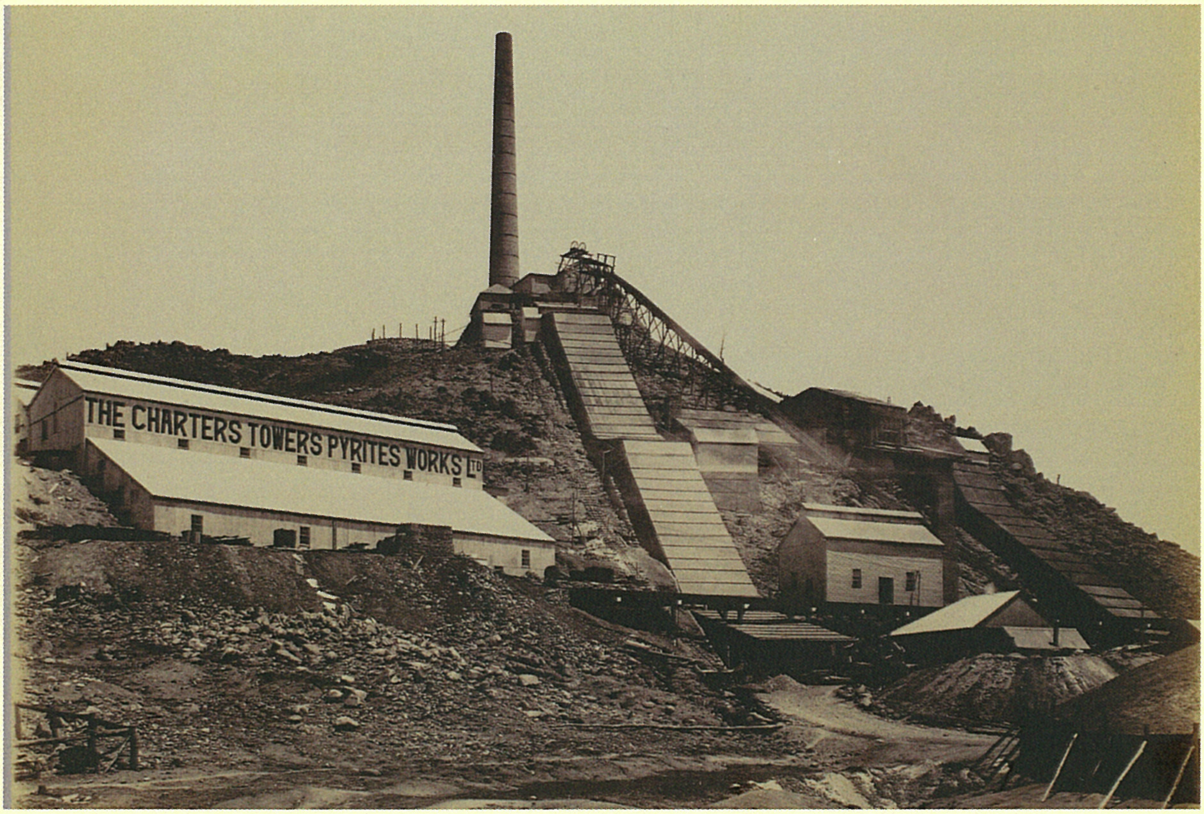

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Evolution of underground coal mine explosion law in Australia, 1887-2007

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Explosions have always been a global life-threatening issue for the coal mining industry. An explosion is a rapid expansion of gases resulting from a chemical or physical reaction that produces pressure waves.[1] Rapid gas expansion may occur due to the fast combustion of methane gas/air mixture, or coal dust particle/air mixture in a confined space. Igniting explosive mixtures can occur by various means including a naked flame; friction, hot surfaces, or an electrostatic discharge.

Coalmine gas is usually composed of methane (CH4) and carbon dioxide (CO2) and is produced with water during the alteration of ancient vegetation into coal. Methane explosions occur in mines when a build-up of methane gas comes into contact with a heat source and there is insufficient ventilation available to dilute the gas to a level below its explosion point.[2]

The methane/air mixture becomes explosive within a range of 5.4-14.8 per cent methane and the most dangerous concentration appears when the methane content reaches 9.5 per cent, which is the optimal oxidation point. The methane and air mixture does not require much energy to be ignited, and a self-heated coal zone is sufficient to kick start the combustion chain. Friction sparks due to a continuous miner and/or shearer drum picks are also the ignition sources for methane gas, while other potential sources are cable flashes, striking quartz or pyrites, naked flames and belt friction.

Once the combustion begins, the heat generated leads to rapid expansion of the gas mixture. Since an underground coal mine is a confined space, which means the ventilation system is usually unable to vent out the sudden increased air volume within the region, the regional air pressure continues to build up and eventually creates a shock wave (explosion) around the combustion area.

Coal dust is a powdery form of coal that is created during the mining process. When the coal is in a lump form, the combusting rate of the coal is not fast enough to be explosive. However, while all coal surfaces absorb oxygen, if coal is broken into fine powdery form, and if the ventilation is inadequate to dissipate the heat generated by the exothermic reaction, it becomes more prone to spontaneous combustion.

Similar to the methane/air mixture, the coal dust/air mixture also has upper and lower explosion limits. The lower explosion limit lies within a range of 10-50 g/m3 depending on the size of the particle. Failure to provide sufficient ventilation to depress the self-heating process and dilute the flying coal dust can lead to a coal dust explosion Such a high concentration of coal dust does not commonly appear in coalmines, but this limit is usually breached by blasting, or by a methane explosion. The shock wave caused by methane explosions can eject coal dust within the mine, and the heat generated by the methane reaction can ignite the coal dust, which greatly intensifies the energy of the explosion.

Stone dust or calcium carbonate is a primary inert agent which prevents a coal dust explosion, since it slows down the flame growth by absorbing the heat that the coal dust would otherwise receive. In a methane explosion, a pressure pulse travels through the immediate area of the mine. A fireball is created that travels behind the shock wave and causes the coal and stone dust to become airborne, and the judiciously placed stone dust barriers to collapse, thus dissipating the impact of the coal dust explosion.

The instantaneous outbursts are defined as violent ejections of coal and gas from the working coal seam. The intensity of a coal outburst is directly proportional to the volumes of the gas that is stored within the coal seams. The gas mainly consists of methane, carbon dioxide, or the mixture of both. The intensity of a coal outburst is the result of a combination of gas content, flow, stress, and coal failure.[3]

Williams and Weissmann use a schematic diagram to represent outburst conditions and highlight a gas pressure gradient existing ahead of the working face.[4] Gas desorption rates were also considered an equally important factor contributing to a gas outburst.

During the early 20th century, the Australian underground coal mining industry suffered from an unacceptably high annual death rate. Today, the Australian mining industry has developed safe working protocols and provides a better working environment for miners. However, accidents and fatalities still occur. Explosive mixture management is especially critical to the safety of a mine. In order to achieve the final goal of zero casualties, this research attempts to figure out the pattern of safety improvement by reviewing the Australian underground coal mine accidents, and the legislative actions adopted by governments.

Methodology

This research is based on case studies of published underground coalmine accident investigations, data collected from government published annual reports, and study of coalmining laws, polices and codes.[5] This is secondary quantitative research based upon published governmental and other statistical data, for systematic empirical analysis of data and phenomena.[6]

The data extracted are based on year, region, accident type and mine size. With these data, flexible and more specific comparisons and studies are possible. All mining laws, policies, industry codes and actions are recorded on a time line, in order to compare their effects. It is observed that the majority of new policies were published after accidents occurred, as a reactive measure to mitigate the chance of previous incident or disaster recurring.

Furthermore, the possible outcomes come in three ways: decrease in casualty rate; increase in casualty rate; and no significant change in casualty rate. In order to understand and study the statistical results, all three possible consequences are analysed.

To study the history of Australian underground coalmine safety, a time period from 1887-2007 is considered. Therefore, annual reports and accident enquires were collected for this period and other evaluations, and professional opinions were sought from industrial experts. Government web pages and published law books also proved valid sources to obtain the critical information.

In Australia most of the underground coalmines are located in New South Wales (NSW) and Queensland. As all the explosions between 1887-2007 occurred in these states, they are the focus of this study. The two states produce more than 95 per cent of black coal in Australia, in about equal shares. NSW accounts for about 80 per cent of underground production, Queensland about 60 per cent of open cut production. NSW currently has 64 operating mines and 16 major development proposals. There are small black coal industries in South Australia (Leigh Creek open cut), Western Australia (Collie open cut) and Tasmania (underground). Brown coal is produced mainly in Victoria. Queensland coal production, which is mainly open cut, continues to grow at a higher rate than NSW. Coal production in NSW and Queensland is concentrated respectively in the Sydney-Gunnedah Basin and the Bowen Basin. As a result, the effects of any developments or changes in the industry on employment have been highly regionalised.[7]

The statistical picture

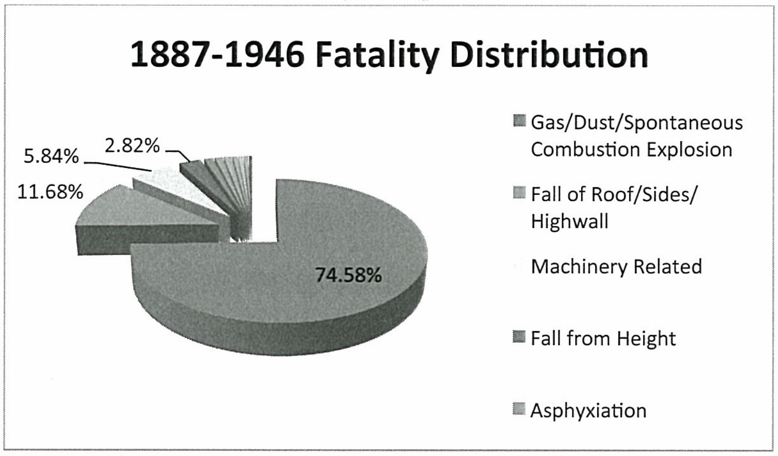
During the early stages of coal mining activity in Australia, coalmine explosions were the most serious hazard faced by the industry. From the Bulli Colliery explosion in 1887 to Moura No. 2 mine explosion in 1994, there were 22 explosions that in total claimed 411 miners' lives (Table 1).[8]

Table 1: *Recorded incidents of Australian coalmine explosions1887-1999*

Number	Location	State	Year	Type of Incident	Fatalities
1	Bulli Colliery	NSW	1887	Explosion	81
2	Dudley Colliery	NSW	1898	Explosion	15
3	Torbanlea mine	QLD	1900	Explosion	5
4	Mount Kembla	NSW	1902	Explosion	94
5	Stanford Merthyr	NSW	1905	Explosion	6
6	Mount Mulligan	QLD	1921	Explosion	76
7	Bellbird Colliery	NSW	1923	Fire and explosion	21
8	Redhead Colliery	NSW	1926	Explosion	5
9	Redbank	QLD	1928	Explosion	4
10	Wonthaggi Mine	VIC	1931	Explosion	4
11	Hart's Aberdare	QLD	1936	Explosion	4
12	Wonthaggi Mine	VIC	1937	Explosion	13
13	Ebbw Vale No3	QLD	1945	Explosion	4
14	Aberdare Extended	QLD	1954	Explosion	2
15	Bulli	NSW	1965	Fire	4
16	Box Flat, Ipswich	QLD	1972	Explosion	17
17	Kianga No. 1 Mine	QLD	1975	Explosion	13
18	Duncan	TAS	1977	Explosion	3
19	Appin Colliery	NSW	1979	Explosion	14
20	Moura No 4 Mine	QLD	1986	Explosion	12
21	South Bulli Mine	NSW	1991	Explosion	3
22	Moura No. 2	QLD	1994	Explosion	11
				Total	411

According to Departments of Mines in the various states, about three-quarters of Australian coalmine fatalities in the period 1887-1946 were caused by underground explosions (Fig. 1). Table 1 shows the explosion statistics of Australia with state, year, number of persons killed and corresponding legislative amendment during the period 1887-2007.

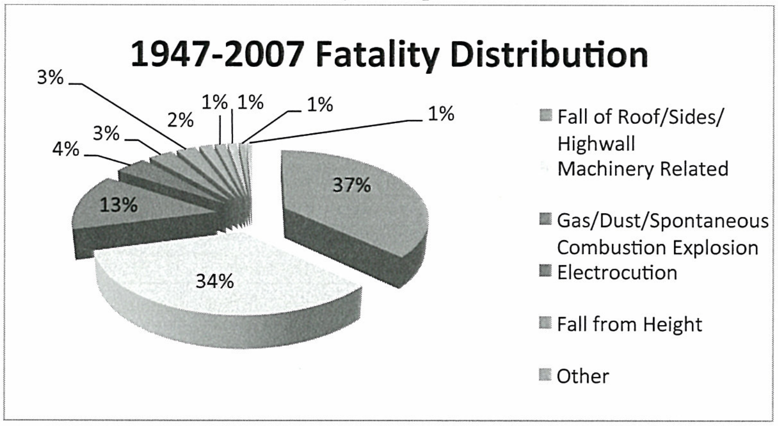
Figure 1: *Fatality Distribution for the period 1887-1946*



Source: Compiled from: Minerals Council of Australia, 'Safety and Health Performance Report of the Australian Minerals Industry 2008 - 2009', 2010; ABS, *Yearbook Australia*, Australian Bureau of Statistics, Canberra, 1908-2008.

In the following six decades, from 1947-2007, the distribution of factors causing fatalities changed significantly (Fig. 2). As noted, the fatalities caused by fall of roof/side/highwall and machinery contributed to two-thirds of the total coalmine fatalities in that period. The percentage of deaths caused by coalmine explosions dropped more than 60 per cent.

Figure 2: *Fatality Distribution for the period 1947-2007*



Source: Compiled from: Minerals Council of Australia, 'Safety and Health Performance Report of the Australian Minerals Industry 2008 - 2009', 2010; ABS, *Yearbook Australia*, Australian Bureau of Statistics, Canberra, 1908-2008.

Figure 2 also reveals that due to the advent of increased mechanization in the mining industry, machinery took over from mine explosions as the most lethal killer for Australian coalminers, despite the last significant fatal underground coalmine explosion being recorded in Moura No. 2 colliery in 1994. Furthermore, as shown in Table 2, the total number of deaths decreased from 1,276 during 1887-1946 to 702 between 1947 and 2007.

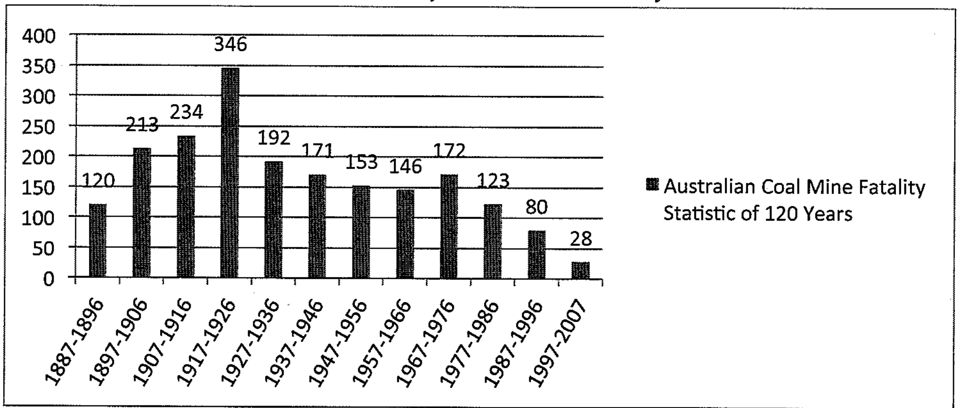
Table 2: *Australian coal mine fatality statistics over 120 years*

Decade	Fatality	Subtotal for each 60 yrs
1887-1896	120	
1897-1906	213	
1907-1916	234	
1917-1926	346	
1927-1936	192	
1937-1946	171	1276
1947-1956	153	
1957-1966	146	
1967-1976	172	
1977-1986	123	
1987-1996	80	
1997-2007	28	702

Source: Minerals Council of Australia, 'Safety and Health Performance Report of the Australian Minerals Industry 2008 - 2009', 2010; ABS, *Yearbook Australia,* Australian Bureau of Statistics, Canberra, 1908-2008.

Figure 3 shows the fatalities per decade experienced in the Australian coalmining industry from 1887 to 2007. From 1887-1926, there is a significant increasing trend in the fatality statistic for four decades, which reached the peak at 346 deaths in 1917-1926. A dramatic fall from 346 to 192 fatalities occurred in 1927-1936, and kept on decreasing gradually until there was a minor increase in 1967-1976. The general decreasing trend of fatalities continued except for a slight increase in the 1967-1976 period, and then dropped steeply until 2007.

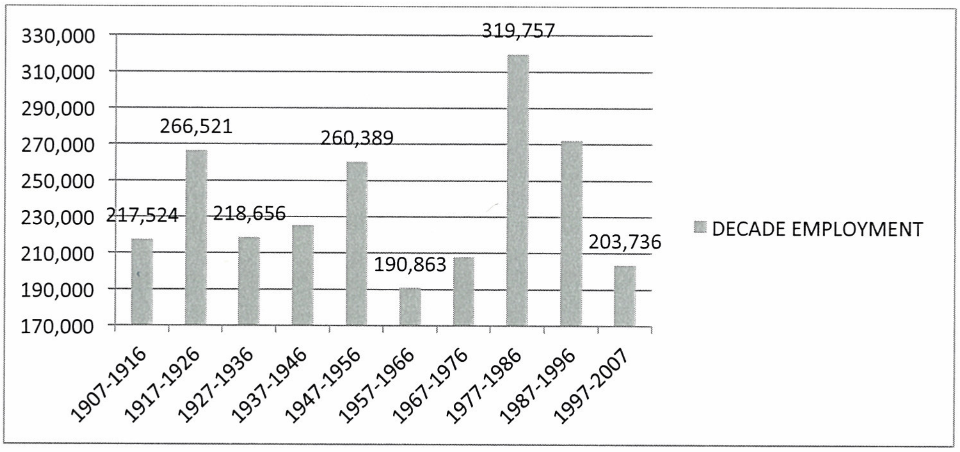
Figure 3: *Australian Coal Mine Fatality Statistics over 120 years*



Source: Minerals Council of Australia, 'Safety and Health Performance Report of the Australian Minerals Industry 2008 - 2009', 2010; ABS, *Yearbook Australia,* Australian Bureau of Statistics, Canberra, 1908-2008.

Obviously, the employment situation should also be considered because exposure to accidents increases with an increasing number of employees. Thus, it would be expected that under similar safety conditions, increasing employment numbers would lead to higher fatality numbers. According to *Yearbook Australia*, employment in the Australian coalmining industry experienced significant fluctuations overtime (Fig. 4).

Figure 4: *Decade-wise Australian coal mining employment from 1907 to 2007*



Source: Minerals Council of Australia, 'Safety and Health Performance Report of the Australian Minerals Industry 2008 - 2009', 2010; ABS, *Yearbook Australia,* Australian Bureau of Statistics, Canberra, 1908-2008.

Employment figures for the Australian coalmining sector between 1887 and 1906 are unavailable. Figure 4 shows that the number of employees in the industry increased by 23 per cent in the period 1917-1926 when compared with the previous decade. As observed in Figure 3, the number of fatalities also increased by almost 48 per cent during that period. During that time, the major part of coal production was carried out by primitive labour-intensive and low technology methods, and production was greatly dependent on the amount of labour deployed. However, the lack of specific occupational health and safety regulations, which was a result of lack of safety awareness in both the administration and workforce, was a blight, especially in the sphere of coalmine methane gas control. Although there was some technical protection available, due to critically low safety awareness within the industry, gas explosions continued to extend the list of fatalities and remained as the top killer of coal miners for decades.

Case studies and legislation

The first mining safety legislation in Australia was introduced in New South Wales in 1854, but its implementation was inadequate, as production remained the primary industrial goal. The legislation that entailed appointment of an examiner and production of mine plans proved weak and ineffective, but another Act was passed in 1862 in response to pressure from miners and the general public to improve the level of safety in mines.[9]

In NSW coal was discovered near Newcastle in 1791, and the first exports were made in 1801. There was no legislation in place to control coal mining until 1854, when legislation based on the British example was introduced. This same legislation was carried to Queensland during separation with NSW in 1859, and for a brief period it can be said common legislation did exist. Not long afterwards, however, Queensland fell behind when the NSW legislation was amended in 1862. Until 1925 Queensland's legislation was similar to that in the UK and NSW but limited in its scope.[10]

Evolution of NSW explosion laws

In 1875, the New South Wales Department of Mines was established and in the following year minor amendments were made, and Coal Mines Inspectors were appointed to enforce the provisions of Coal Mines Regulations Act (CMRA). Filing of reports commenced in 1876.

On Wednesday, 23 March 1887, at 2:30 p.m., an explosion occurred at the Bulli Colliery in NSW that resulted in the deaths of 81 men and boys. At the time this was Australia's largest coalmine disaster and today remains the second worst after 1902's Mount Kembla disaster which took the lives of 96 mineworkers. Bulli Colliery was a gassy pit having high concentrations of firedamp (methane) within its coal and the circulating air was delivered by a ventilation system to dilute and remove the methane gas before it built up to a critical level. Although safety lamps were used, the explosion was recorded as being caused by a methane-dust combined explosion ignited by a naked lamp.[11]

From 1876, once the existence of gas was established, this had to be reported immediately to management, and safety lamps had to be distributed to miners in an affected section.[12] However, the issue of safety lamps was an unpopular one with miners because they gave off a very dim, flickering orange coloured light. This caused annoyance among piecework miners who went on strike at Bulli. After the strike the first deputy, James Crawford, was not re-engaged and his replacement, Robert Millwood, did not bother to lock the lamps most of the time. Miners took advantage of Millwood's casual style of management by working with unlocked lights in gas-laden sections of the mine, despite the presence of firedamp.[13]

The safety lamps at Bulli were only locked with a simple device that could easily be unlatched with any sharp implement.[14] During one nightshift when no deputy was on duty, the men opened their lamps by using the key that had been left behind for that purpose by Millwood on the previous shift.[15] There was obvious tolerance from the deputy towards the use of naked lamps, which was a gross violation of the Coal Mines Regulation Act of 1876.

A legislative body that involved several mine owners originally drew up the original framework of the CMRA of NSW. It is not surprising that these parliamentary coalmine proprietors were averse to introducing legislation that would impose heavy costs on the industry associated with the provision of the required safety measures. A great weakness of the 1876 CMRA was that it did not give Department of Mines Inspectorate the power of prosecution and once the Act was established few authorities, apart from the Department of Mines, ensured that the Act was adequately observed. The inspectorate's pronouncements were almost always unchallenged and its judgements invariably endorsed at ministerial level.

Although major amendments in the CMRA of NSW were made in 1889, just two years after the Bulli accident, this bill was not implemented until 1896 because 22 of the legislative councillors and 25 members of the Legislative Assembly were coalmine owners who believed that this bill would deeply harm coalmine profitability. The most significant change in legislation was to place the responsibility for mine safety on the Colliery Manager and, further, to provide certificates of competency and examinations for statutory mining officials. [16] According to the Premier (himself a colliery owner), the new bill was a response to the 'state of panic' generated by the Bulli disaster and might well, he thought, render coal mining impossible by making it unprofitable.[17]

The amendment brought in some major changes including that of making a Colliery Manager responsible for mine safety; the introduction of examinations; and introducing certificates of competency for statutory mining officials. The first Chief Inspector of NSW Coal Mines, Mr A.A. Atkinson, was appointed in 1897 to administer the Coal Mines Regulation Act (CMRA) and direct the operations of Coal Mines Inspectors of NSW.[18]

However, legislation was not sufficient to prevent the Dudley Colliery Explosion in which 15 men were killed on March 21 1898,[19] nor was it sufficient when four years later, the Mount Kembla explosion occurred in NSW. With 96 men and boys killed on 31 July 1902, it remains Australia's greatest land-based peacetime disaster. The cause was a methane and coal dust combined explosion. Unlike the Bulli Colliery, this mine was widely believed to be free from danger of gases, for it was reported that gas had never been known to exist in the mine before, and that the mine was one of the best ventilated in the State. The Commission of Enquiry concluded that substitution of the flame lamps by safety lamps could have saved the 96 lives.[20]

On Sunday 29 October 1905, a massive fire and explosion occurred at the Stanford Merthyr coal mine, Kurri Kurri (owned by the East Greta Coal Mining Company) resulting in the death of six men, with others receiving serious injuries. The six fatalities made up 31.6 per cent of the total deaths recorded in New South Wales's coal and shale mines in 1905. The disaster had some unusual features: it occurred when no one was working underground; those killed were all 'officials' of the company; and five out of the six deceased were Welsh immigrants.[21]

In 1907, a set of special rules was prepared dealing with the use of electricity in coalmines. In 1908, the CMRA was amended to provide for the certification and appointment of electricians and the appointment of an Electrical Inspector. [22]

Complete re-enactment of Legislation in NSW, which was mainly a consolidation of amendments that had been made since 1896, was introduced in 1912, well after the Mount Kembla (1902) and Stanford Merthyr explosions (1905).

In 1920, a bill was drafted to compel the use of fans instead of furnaces to ventilate new mines employing more than 30 persons underground. Although stone dusting regulations were introduced in Great Britain in 1920, these could not be enacted in NSW, despite its four coal dust related explosions, because a deputation of Mine Managers met the under Secretary of Mines claiming that it wasn't necessary to have stone dusting regulations in the state.[23]

There was another explosion at Bellbird Mines, NSW in 1923 that killed 21 miners.[24] Subsequently, a major revision of the 1912 NSW Act was enacted in 1926, with inclusion of additional regulations for ventilation, explosives, coal dust, use of safety lamps or electric cap lamps, and the duties and powers of inspectors.

Clearly, gas detection and safety awareness during that period were still far from adequate, and methane explosions were commonly believed as inevitable within the industry. Despite the heavy losses brought by these coalmine disasters, flame lamps were used in coalmines until the 1940s.

Further revision of the 1912 Act of NSW CMRA was undertaken in 1941, which embodied many recommendations of the findings of the 1938 Davidson Royal Commission on Safety and Health. These amendments provided for tightening of the rules for the control of explosives, the supervision of shotfiring, improvements in ventilation, the prohibition of naked lights in all mines and the substitution of electric safety lamps, and the supply by owners of protective equipment.[25] In this amendment, stone dusting regulations were also modified to be in line with the practice adopted in Britain in 1920.[26]

Another serious explosion at Old Bulli Mines, NSW, killed 4 miners on 9 November 1965, and consequently further legislative amendments were introduced following the 1965 Goran Inquiry into the disaster.

A watershed for global Occupational Health and Safety [OHS] legislation and practice occurred in 1972, when Chair of the National Coal Board in the United Kingdom, Lord Robens, delivered a report to Parliament into Safety and Health in Work in the UK. A key finding of the Robens report[27] was that the regulations were too complicated in OHS, and needed to be simplified. He recommended that where necessary, a broad framework of laws should be supported by specific regulations, codes of practice and guidance. Crucially, he found that the balance between 'prescriptive' and 'goal-setting', or enabling legislation needed to shift towards the latter and that self-regulation should be encouraged. Accompanying this last point were recommendations for the OHS Inspectorate to undergo significant reform in order to adapt to these changes in approach.[28]

Between 1973 and 1989 the Australian federal and state governments all enacted laws based on the Robens Model, but embellished with a variety of local and other international influences. At this stage, the conventional prescriptive legislation was questioned as being insufficient for the further improvement in industrial safety and health. A major revision of the NSW Coal Mine Regulation Act was subsequently carried out in 1973, as it was suggested that the Government needed to adopt a new approach in order to further improve industrial safety performance.[29] The changes introduced gained positive results in the following decades. The death rate dropped rapidly by more than 50 per cent in 1977-1986, and kept on dropping until 2007. It is notable that employment peaked at 319,797 in the period 1977-1986, the highest figure in Australian coal mining history, while the death rate was lower than in all-previous decades.

A further concern to introduce changes came out of yet another serious incident on 24 July 1979, when there was an explosion in the K-panel section of Appin Coal mine situated in the Southern Coalfield NSW during the night shift, which resulted in the loss of 14 lives. The explosion was caused by a dangerous build-up of gas. Prior to the explosion, the auxiliary fans failed to function properly, and an electrician was called in. The electrician, who wanted to test the fans after fixing them, closed the metal box and only tightened one bolt with two turns. The box was not flameproof and thus initiated the explosion. In an article on the affair, A. Hopkins wrote that according to Judge Goran who was involved in the inquiry, there was a 'general attitude of carelessness for regulation'. He noted the company management had not used 'all reasonable means' to enforce the rule which the electrician had breached.[30] Regulations were in place to prevent initiation of such an event involving the prevention of formation of dangerous gas concentrations, and elimination of all sources of ignition, but these had been ignored.[31]

Following this 1979 Appin disaster, further amendments to the Legislation were made in 1980, followed by a major revision in 1982. Drafting of a new CMRA had been commenced in the mid-1970s following publication of the Roben's Report 1970-72, and this report, plus the various disasters influenced the NSW Government on the need to adopt a 'fresh' approach to industrial safety and health.[32]

In summary, the NSW Coal Mines Regulation Act 1912 was followed by the Coal Mining Act 1973, followed by Coal Mining regulation Act 1982, and finally the Coal Mine Health and Safety Act 2002 (CMH&SA2002). This was eventually supported by the Coal Mining Health and Safety regulation 2006 (CMH&SR2006). The Act and regulations combine the requirement to develop health and safety management systems and major hazard management plans through a process of consultation with mine workers.[33]

Evolution of Queensland's explosion laws

Queensland became a separate state in 1859 and the existing NSW mining law was adopted by the new state. Community pressure impelled the first Queensland Act regarding safety in mines and collieries in 1882.[34]

Following an explosion of gas on 21 March 1900 at the Torbanlea mine in which five men died, a Royal Commission was appointed. The findings of that Commission were not acted on until 1910 when a new Mines Regulation Act was passed incorporating most of the recommendations of the 1900 Royal Commission. The act included i) certification of managers, ii) control of explosives, and iii) appointment of a Chief Inspector. In 1912, amendments were made, including i) appointment of shotfirers, and ii) rules for use of electricity.[35]

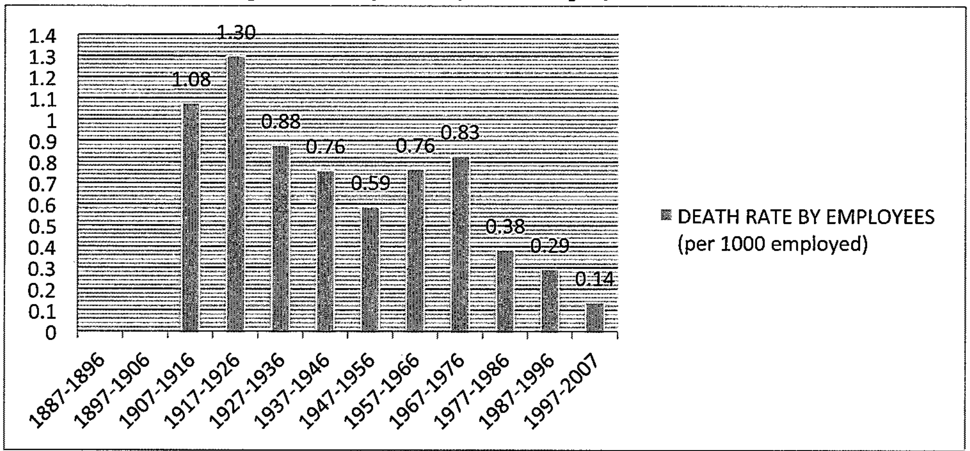
Until 1925 the Queensland Act combined coal and metal mines and was a limited affair in comparison to both existing British and NSW coalmining acts. The Mount Mulligan disaster in which 75 men had died in 1921 prompted the first targeted legislation in Queensland, when the separate Coal Mining Act (CMA) 1925 was introduced.[36]

The Mt. Mulligan disaster occurred on the morning of 19 September 1921, when a massive explosion occurred. A heroic rescue effort that began within minutes of the explosion, and which persisted for five days with the assistance of several hundred volunteers from the surrounding district, proved quite fruitless. This was the greatest land disaster Queensland has seen, and its local impact has never been paralleled elsewhere in Australia: the men killed in the explosion were about a quarter of the entire population of the town; about one adult in three; or one adult male in every two. They left about 40 widows and 83 fatherless children.[37]

In Queensland's CMA 1925, provisions were made for the appointment of Mines Inspectors who were required to have practical mining experience. Regulations required the recording of mine deputy safety inspections and new standards were set for specifically designed and permitted explosives. Regulations were also introduced regarding the use of safety lamps and the banning of naked lights, the application of stone dust, the establishment of mines Rescue Stations in all mining districts, and rules for air flow and the use of ventilation fans.[38]

In Queensland one more disaster occurred at Collinsville on 13 October 1954, in which 7 miners were killed in a carbon dioxide outburst. The Queensland CMA 1925 was then further amended to require Mine Deputies to undertake statutory examinations for qualification before appointment, and for Deputies to carry flame safety lamps and gas detectors during inspections.[39]

Figure 5: *fatality rate per decade for every 1000 employed*



Source: Compiled from: Minerals Council of Australia, 'Safety and Health Performance Report of the Australian Minerals Industry 2008 - 2009', 2010; ABS, *Yearbook Australia*, Australian Bureau of Statistics, Canberra, 1908-2008.

While Figure 5 shows a notable improvement in safety performance per decade from 1927 to 1956, this was not the case for the decades between 1957-1976. In Queensland during that period three explosions occurred in 1972, 1975 and 1986.

The first occurred on the 31st July 1972, when a gas explosion in the No. 5 mine of Box Flat Extended Collieries cost 17 lives. According to the inquiry carried out at that time, spontaneous heating occurred in a pile of fallen coal in the No. 2 level of No.

2 South Section, on the weekend of 29-30 July 1972.[40] After that, a ventilation fan was stopped for 11 hours and caused reduced flow of the air that was required to prevent heat accumulation to self-ignition, a situation later proved by the presence of fumes in the intake airway. The heating process then ignited the methane/air mixture; it turned into a large fire, and all protective efforts failed. This caused an explosion to take place due to the explosive mixture of gases and coal dust.[41]

The Commission team that investigated the matter came up with several valuable recommendations and formed a Safety in Mines Organization in conjunction with the New South Wales coal mining industry. The main focus of this team remains the design and delivery of practical demonstrations to train miners how to deal correctly with emergency situations. It was commendable to see the industry pay more attention to educating personnel and to provide safety training, something that had long been lacking in its emphasis. The organisation also stressed: i) the development of new fire-fighting techniques, ii) the use of stone dust, iii) regular atmospheric sampling, iv) ventilation surveying, and v) reduction of spall in coal ribs.[42]

However, that was not the end of disastrous occurrences in Queensland, as another spontaneous combustion occurred at Kianga No. 1 underground mine on Saturday, 20 September 1975, which killed 13 miners. An Inquiry, conducted by the Mining Warden with assistance from four persons having practical mining knowledge, commenced on 10 November 1975, and closed on 24 November 1975. It found that the explosion was caused by a spontaneous combustion source which ignited flammable gas and which was propagated by coal dust. Recommendations were generally addressed on ventilation and atmosphere control aspects, as the coalmines in Kianga area were known to be both gassy and liable to spontaneous combustion.[43]

Following this explosion, further legislative changes were made to the coalmining Acts in Queensland that saw, i) the introduction of explosion-proof barriers, ii) a requirement for a barometer (to measure changes in barometric pressure affecting ventilation underground) to be available on the surface of each underground mine, iii) a requirement for the provision of continuous carbon monoxide (CO) monitoring, and recording of gas ratios and trends, and iv) the requirement for the construction of preparatory seals to enable rapid sealing of underground sections in the event of heating or a fire.[44]

Despite the above changes, at about 11:05am on 16 July 1986, an explosion in Moura No. 4 Underground Mine in Central Queensland took place. The 12 miners who were extracting pillars in the Main Dips Section were killed. Despite safety measures appearing to be adequate, disaster still occurred. The Warden's enquiry revealed that the reason for this disaster was a roof fall, which triggered the release of methane that created a rich methane/air mixture. This was highly concentrated in a coal dust environment, resulting in development of an explosive atmosphere in the working area, and in particular around the deputy's flame safety lamp.[45]

It was noted that the mine was equipped with a well designed ventilation monitoring based on the use of methanometers, and the last air quality survey, carried out on 24th June 1986, showed the methane reading as 0.2-0.3 per cent throughout No. 5 heading to the main dips, a reading that proved the mine ventilation system performed well. In addition a water barrier had been installed between belt headings 23 and 24 as required by The Coal Mining Act 1925-1981.[46] Other possible ignition sources included fire or spontaneous combustion, electrical apparatus and cables, electrostatic discharge, mechanical equipment and safety lamps.[47]

The Warden's inquiry ultimately resulted in the Act and/or regulations being further amended to provide for i) the banning of flame safety lamps from underground mines, ii) the banning of aluminium alloys from underground, iii) continuous gas monitoring from all sections of the workings, with readings to be available on the surface of the mine, iv) safety induction training to be compulsory for all mineworkers, and v) secondary extraction plans to be developed and approved by the mines Inspectorate.[48]

Initially, prescriptive legislation was viewed as the panacea for all safety and health issues. A classic example was the removal of Oil Flame Safety Lamps (OFSLs) following the Moura No. 4 disaster in 1986. However, prescriptive legislation was not working, as evidenced by continuing fatalities and disasters. This is illustrated by the underground explosion in 1994 at the Moura No. 2, that resulted in the death of 11 men at the Southern area of the mine. Rapid mining and extraction of coal within the six-month incubation period was expected to eliminate the potential for spontaneous combustion of the coal at the mine. The events that occurred, however, proved that this was an inadequate measure.[49]

According to the innovative design in Moura No. 2, there were some unintended consequences of allowing loose coal to accumulate around the columns and under the floor ramps. There were also some localized roof falls during the retreat that might have concealed loose coal. The problem with loose coal is its potential exposure to oxygen in the air, which spontaneously starts a heating process. When very hot, the coal can trigger an explosion if combustible gases are present.[50] Good ventilation is the main means of preventing the coal from heating, but the ventilation system in operation in the 512 panel at Moura was obviously inadequate.

The Moura disaster led to further substantial amendments to the Queensland CMA 1925. The Warden's enquiry ultimately saw a legislative requirement for, i) risk based Safety and Health Management Systems including the development of a Principal Hazard Management System at each mine in consultation with mine workers, ii) spontaneous combustion and gas management training for all underground mineworkers, iii) simulated emergency exercises to be conducted annually at each mine and at State level at a selected mine, iv) a Ventilation Officer to be appointed at each underground mine and for such a person to be in full charge of all aspects of ventilation at the mine, v) oxygen self-rescuers to be supplied for each mine worker, vi) statutory officials certificates to be no longer available for life, but valid for 5 years, vi) sealing plans to be developed, and persons to be withdrawn after sealing, vii) supervisors to be trained and be competent in communication, risk management and such other competencies as determined by the Advisory council.[51]

Although some specific regulation and standards were followed and all essential systems were installed properly, the protective barriers were still fragile when facing complicated multiple hazard situations. In this case the ventilation and monitoring systems were well designed to remove all the regular methane gas emissions in the underground levels, and to maintain the gas content well below 1 per cent except for sudden regional methane leakages from roof falls. Following this disaster, it became obvious that a more advanced risk management regime was required in order to deal with complicated safety situations.

Mine Rescue Organisation

A possible direct reason that contributed to the drop of fatalities since 1927 (Fig. 5) was the enactment of several major legislative changes. These included the passing of the Mines Rescue Act 1925 in NSW that was a reaction to the accumulated toll of fatalities. It was based on trade union policy and placed safety regulations on the coal industry, including the establishment of purpose-built rescue organizations and stations to protect miners' lives and mining property. The first mines rescue facility in the Hunter Valley was the South Maitland Mines Rescue Station. They relied heavily on the Proto apparatus, which allowed them to enter mines where the air was contaminated with deadly gasses.[52]

In 1926, the building of four rescue stations in four coalmining districts in NSW was completed. Mine rescue stations were, and still are, located in the following mining districts: i) the Newcastle Mines Rescue Station at Boolaroo, ii) southern Mines Rescue Station at Wollongong, iii) the Hunter valley Mines Rescue Station at Singleton, and iv) the Western Mines Rescue Station at Lithgow. An unmanned substation was later maintained at Ulan.[53]

In the same period the Queensland legislators also recommended setting up mine rescue stations in all mining districts. The subsequent improvements were significant, and prescriptive legislation was believed to be the cure for all safety issues. In 1925 Queensland mine rescue stations were established with the approval of the Department of Mines, State Government Insurance Office and an industry committee in three locations: Northern, Central and Southern, each having its own management committee. In the mid 1990s the three committees amalgamated into one management committee to control the five mines rescue stations that were located as follows: i) Southern Queensland at Booval, ii) Central Queensland, two stations, one at Moura and the other at Blackwater, and iii) Northern Queensland, two stations, one at Dysart and the other at Collinsville.[54]

In 1996, the Queensland Government withdrew funding from mine rescue services and the industry assumed full responsibility. A public company was established called the Queensland Mines Rescue Service (QMRS), which is owned collectively by all registered coalmines. In 1998, the Coal Mining Act of 1925 was amended and QMRS became an 'accredited operation' to provide mine rescue services. Currently, QMRS has its head office at Dysart rescue station.

Comparison

Both the Queensland and NSW coalmining legislation contain a mixture of prescriptive requirement and enabling provisions. Prescriptive requirements are related to technical requirements such as the permissible gas level and reporting of high potential incidents to the Inspectorate. The enabling provisions cover a range of matters such as conduct of inspections; development of safety and health management systems; development of standard operating procedures for defined hazards and hazardous tasks, etc. The Act and the regulations in both jurisdictions were developed utilizing risk management ideals and principals, and in Queensland the legislation adopts the concept of the achievement of an 'acceptable level of risk'. In NSW the legislation is subordinate to the Occupational Health and Safety Act that purports to place an 'absolute' duty on the employer to provide safe place of work.[55]

A feature of the jurisdictions under legislation in both the states is that Operators are required to ensure that Safety and Health Management Systems are developed through consultative processes at each mine. Both acts have a feature of specifying Principal Hazard Management plans, or Major Hazard Management Plans, to be developed to address the risks associated with specific hazards that are recognized as existing at mines.[56]

Conclusions

Over a period of more than a century, a sophisticated legislative system was built that enhanced and dramatically improved coalmine safety performance. More than 75 per cent of coal mine fatalities were caused by gas explosions in the early 20th century, while this figure came down to 13 per cent over the six decades between 1946-2007. In addition there has been a significant improvement in the control of coalmine methane explosions. Coalmine explosions are no longer contributing to a majority of fatal accidents, thus directly resulting in an impressive drop in total fatality numbers. Structural failure (such as roof falls) and machinery accidents have gradually become the greater issue. As to continuing amendments to existing regulations, the focus of the future legalisation will move on to specific regulations for specific mines, which will be determined by different geological conditions, mining methods and other specific conditions.

Currently, the Australian coalmining industry still witnesses several types of fatal accidents from machines, collapsing roof outbursts from the ribs, and other occurrences. The industry is still some distance from the ultimate goal of eliminating all sources of accidents.

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