Title of paper: **Current trends and future opportunities in underground hardrock ventilation practices**

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ABSTRACT

The Australian mining industry has changed dramatically over the past 20 years in terms of mining methods, mining equipment and human resource policies. The industry's approach to safety and health in terms of attitudes, style of legislation, and risk management techniques has also changed significantly. These changes have had and continue to have major impacts on the design of underground mine ventilation systems. In some areas, trends are clearly emerging. In other areas, mine ventilation planning remains very "reactive" and is performing poorly in terms of providing a safe and healthy work environment at a reasonable cost. New concepts involving the role of ramps and shafts, the provision of refrigerated air, "ventilation on demand" and new egress and entrapment approaches are likely to be incorporated into mine planning and operating practices over the next 10 years. This paper discusses these and other trends and identifies some likely future developments in the area of hardrock mine ventilation.

INTRODUCTION

Traditional hardrock mine ventilation practices in Australia were often developed around large, long-life, shaft-access mining operations with very high tonnes per vertical metre, such as Mount Isa, Broken Hill and Mt Lyell. However, underground hardrock mines in Australia now use very large mobile equipment, much larger development sizes, usually truck to surface rather than use underground crushing and hoisting, may even be moving towards conveying to surface rather than use shaft crushing/hoisting, often have low tonnes per vertical metre, short lives and are trending towards much deeper (and hotter) operations. Many items of plant now have air-conditioned cabins. In addition, mining legislation is trending towards duty of care rather than prescriptive regulations and some States now regulate their mines using generic workplace health and safety legislation rather than mining-specific regulations. Concerns about diesel particulates and problems with traditional approaches to second means of egress and aided rescue using mine rescue teams are also impacting significantly on ventilation design. Fly-in, fly-out operation is impacting on the availability of ventilation staff and advice to be on site at all times. Cost pressures and generally lower grade orebodies are resulting in a trend towards mass mining methods such as sub-level caving. Auxiliary ventilation is becoming more critical in most operations, as cost pressures reduce the economic ability to create flow-through ventilation on working levels, or to provide dedicated return air collection horizons. The use of remote loaders (and open drawpoint brows) has become common, which results in stopes short-circuiting between levels. Surface ramps are also now often the principal (or only) intake, making provision of fail-safe fresh air bases impossible.

IMPORTANCE OF VENTILATION IN HARDROCK MINES

It is frequently the case that mine management fails to understand the importance of ventilation in a hardrock mine. One Canadian study found that workers complained more to Mines' Inspectors about ventilation than any other single topic (Crocker, 2002). In addition, gas management and other coal mine ventilation issues are not as uncommon in hardrock mines as might be expected. Consider some of the following examples, all relating to *hardrock* mines:

- One Australian hardrock mine currently has problems with hydrogen as strata gas. SIMTARS has been on site and a coal-based gas drainage specialist has been engaged to advise on options. There is regular “popping and banging” due to minor ignitions.

- Another Australian hardrock mine currently has problems with CO_2 accumulations in the mine. The surrounding strata are carbonates and CO_2 builds up in poorly ventilated areas. This operation has had several instances with miners becoming affected by CO_2, even losing consciousness. The operation has CO_2 sensors and a telemetric system installed on major return airways.
- An Australian hardrock mine currently has methanometers installed in all diamond drilling recesses. Special ventilation is set up in these sites. Drillers are trained to recognise telltale signs of methane gas in the drill water.
- Other operations have had similar problems with H_2S gas in drilling water.
- Another Australian hardrock operation has significant issues with radon gas and radon daughter products. A number of ventilation strategies applicable to gassy coal mines have relevance to this operation.
- The Mount Isa mine in Queensland has a large high-grade orebody that was subject to spontaneous combustion when attempts were made to extract it in the 1960s. The ore was so susceptible to spontaneous combustion that broken ore would increase its temperature to over 1000 ^{0}C. Large quantities of SO_2 and CO_2 were also produced. Underground loader tyres would catch on fire. The orebody remains unmined to this day.
- Several hardrock operations have had problems with SO_2 and H_2S strata gas.
- Many hardrock mines have reported problems with NH_3 (ammonia gas) being produced when ANFO (the most common underground explosive) dissolves in water and comes into contact with lime from cement also dissolved in water, which results in an exothermic reaction producing ammonia.
- A number of hardrock operations have had significant incidents with sulphide dust explosions which have had serious cost and safety implications.
- Potash, Trona and other evaporite mines in overseas operations have had serious gas management/dilution issues with several strata gases and outbursts of CO_2 and N_2.

- A number of hardrock mines in Australia have had problems with windblast, with the Parkes mine in NSW suffering from a major windblast in the past five years that resulted in a multiple fatality.
- Almost all gold and platinum mines in South Africa experience problems with flammable gas and several have had problems with gas outbursts. Between 1989 and 1999, there were 25 fatalities and 36 serious injuries due to flammable gas issues in South African hardrock mines. The average gas concentration across all mines was 66 % methane and 26 % hydrogen (Cook, 1998).

Therefore on the basis of gas management alone, hardrock mines as a group have the potential for significant safety and cost consequences. The additional issues of dust, diesel particulates, heat and egress and entrapment are further issues that are significant in their own right.

NEW AND EMERGING TRENDS

Changes in technology

The relentless drive to increased productivity, reduced costs and improved safety has seen the development of much larger and more productive mining equipment:

- Raise boring machines have generally replaced handheld "raise miners" or Alimak miners for vertical shaft development.
- Large diesel mucking units have replaced compressed air operated or electric/battery units.
- Most new diesel equipment underground now includes air-conditioned cabins.
- Electric-hydraulic trackless development jumbos have replaced hand-held mining and rail-mounted (tracked) equipment.
- The labour-intensity of many mining activities has been reduced by automatic rod-handling equipment, scissors-lift platforms, etc.

Larger diesel equipment

Diesel mobile equipment first went underground in Australian mines in the early 1960s with the emerging trend becoming very well developed by the mid to late 1960s. From 1967 to 1977, the total volume of fresh air in Ontario mines doubled for no change in mine production (Stachulak and Conard, 1997). The introduction in the 1980s and

1990s of even larger diesel units (the AD55 underground trucks currently in use in Australia have 485 kW diesel engines and even larger trucks are being introduced) is pushing mine operators towards ever-increasing airflow requirements, based on the typical design criterion of 0.04 or 0.05 m^3/s per rated engine kW. These big diesel engines need large volumes of air, but only where and when they are working. If the big diesel engine is very mobile (as is frequently the case), then many areas in the mine may be "over-ventilated" on *average* (but clearly *not* when the big diesel is in that area). These factors have meant that the small amounts of air that an underground mine required in the "pre-diesel" era are now significantly insufficient with the large number of high-powered diesels in use. The airflow requirements for Australian mines will continue to increase as diesel equipment sizes increases, even though the size of the workforce is decreasing as productivity improves. Offsetting this, there are promising developments overseas with the use of fuel cells in underground diesel vehicles, which have been trialled in at least two mines in the USA.

Larger development

Another impact of the introduction of larger diesel equipment has been that underground mine tunnels have become substantially larger in the past 40 years. Standard development sizes in the early 1960s were typically 3 m x 3 m, frequently even smaller; however, by the 1990s standard development size was often about 6 m x 6 m. This is a four-fold increase in development cross-sectional area and has in some cases greatly reduced the overall mine resistance. The increased development size is also impacting on both the distances that can be mined before flowthrough ventilation is established, and the required airflows for auxiliary ventilation to maintain minimum acceptable wind speeds. For example, a wind speed of 0.5 m/s in a 3 m x 3 m heading would require an airflow allowance of 4.5 m^3/s, but in a 6 m x 6 m heading, the same wind speed of 0.5 m/s would require an airflow allowance of 18 m^3/s. Partially offsetting this, there have been other factors increasing the mine resistance.

Another impact of larger development is that the forcing duct (the normal auxiliary ventilation setup in hardrock development headings) is not "sweeping" the face as clean as was the case with a single duct in a smaller heading. The use of supplementary ventilation at the face, such as air movers, or changing the standard to ensure the duct terminates closer to the face than in the past, is required to keep gas or dust levels at satisfactory limits.

Ventilation on demand

The problem of mobile equipment that is both very large and very mobile makes it difficult to supply sufficient airflow for all situations and all locations. It would be desirable for the airflow to "follow" (increasing or decreasing) the workers or equipment as they move around the mine. This has resulted in a number of research projects (mainly in Canada) aimed at modulating airflows on a real-time basis to match the mobile equipment as it moves around the mine or as workers change workplaces. However, this requires real-time adjustments to regulators or fans and, whilst demonstrated in experimental mine situations, has yet to be employed successfully in normal operations. Such a system also requires highly reliable ventilation controls that can withstand the sort of punishment typically encountered in an underground environment from blasting and operator use. Therefore, better quality and better engineered ventilation controls (doors, regulators, etc) are likely to be developed and brought onto the market in the next five years. Another factor driving real-time airflow management is the trend towards the use of refrigerated air, which is expensive and therefore needs to be used efficiently. The popular Australian ventilation modelling software, Ventsim™, now has the facility to be connected to real-time underground airflow monitoring sensors and predict airflow changes. It is probable that some form of "ventilation on demand" will come to be considered good practice in the next five to ten years.

Primary, Secondary and Auxiliary fan technology

Fan manufacturing companies are now providing a greater variety of fans with improved ability to meet the challenge of increased airflow at higher pressures.

In 1964 the maximum pressure available from a surface primary axial fan was about 1.1 kPa. The introduction of diesel equipment at this time greatly increased the airflow requirements in underground mines, and with airway sizes still small, fan pressure requirements also increased significantly. Required fan pressures were sometimes greater than a single fan could produce. This was one of the reasons that led to Mount

Isa, for example, installing fans on the downcast shafts and on the upcast shafts utilising the ‘push-pull’ system of primary ventilation.

Recent primary fans installed in Australia have had motors up to 2400 kW with pressure capabilities up to 4.7 kPa.

Underground auxiliary and booster or circuit fans have also changed significantly. In 1964 the largest auxiliary fan used at the Mount Isa mine was a 10 kW 610mm diameter fan producing 4 m^3/s at 1 kPa. Australian mines now regularly use 180 kW and even 220 kW auxiliary fans to ventilate headings with in excess of 50 m^3/s and pressures approaching 5.0 kPa. When installed in series, duct pressures of up to 10 kPa may be experienced. This in turn has also led to new developments in duct technology, with heavier, stronger fabrics, special sealing and sewing techniques and special joins and hanging arrangements required to safely carry and sustain such high pressures.

Likewise the largest flexible duct available in the early 1960s was 610 mm diameter; today ducts of up to 1400 mm diameter are common with 1600 mm ducts starting to be used. Larger ducts allow longer distances to be mined before establishing flowthrough ventilation, which can save considerably on expensive flowthrough connections. In addition, larger ducts allow for multiple take-offs allowing several headings to be ventilated from the one duct. In the past, ducts were typically 20 m in length; ducts are now commonly 50 m or 100 m in length to reduce leakage and frictional pressure losses. However, these ducts are expensive to purchase and install and do need sufficient headroom and a properly planned drive profile (including the height of the break-offs from the main drive) to be fully effective.

Single headings of up to 3000 m have been developed with flexible duct in Australian mines within the past five years, sometimes avoiding the need to put in costly and time-consuming intermediate connections to surface.

Circuit (booster) fans in the 1960s had 30 kW motors producing approximately 30 m^3/s at 600 Pa. Today’s underground booster fans are up to 10 times this motor capacity.

Ramp access

Most Australian mines now have a ramp connecting the surface to the underground workings to improve access into the mine. The high additional upfront capital cost and production delays associated with an underground transport system consisting of orepasses, crusher and hoisting shaft has meant that trucking to the surface has almost completely replaced hoisting. Australian operators prefer to keep this surface trucking and access ramp in fresh air, which has a number of consequences:

- The ramp usually takes on the role of the mine's principal intake and frequently its only intake, which increases the mine resistance due to the length of the ramp compared to an equivalent vertical shaft.
- Similarly, the quality of the intake air decreases due to the presence of diesels discharging their heat, dust, gases and fumes into the air that is then distributed to the working places. This is aggravated by the length of the intake (compared to a shaft) which increases the time available for pick-up of heat and other contaminants.
- In most cases, there is no fresh air shaft so that there are no secure fresh air bases in the mine acting as places of refuge in the event that the ventilation system becomes polluted.
- The shaft is usually the exhaust, so that any ladderway installed in the shaft as the second means of egress is being installed in the principal return airway. This can be argued to be similar to a surface building instructing personnel to "use the lifts" in the event of a fire!

There are a number of reasons why it could be desirable to "reverse" the ventilation design in these "ramp-intake" mines and use the single shaft as the intake:

- Faster intake air transit time
- Less heat pickup and no pickup of gases and dust, and no diesel pollutants
- A truck fire in the ramp becomes a fire in the mine exhaust, with any products of combustion leaving the mine
- The primary ventilation would use a surface forcing (blowing) fan which provides more secure fresh air bases and much better second means of egress

Unfortunately, some Australian states almost legislate against using the surface ramp as the mine exhaust. This is in contrast to most Canadian mines, which usually operate with their surface ramp as the exhaust and their shaft as the intake because they must heat the air before it enters the mine, and this is most practical over the top of a shaft not a portal. This is analogous to the growing Australian situation where the air must be chilled before going underground. Some South African mines use both surface forcing (blowing) fans on the intake and surface refrigeration on the intake. This provides a very secure system of fresh air bases with chilled air for underground workers.

Using the ramp as the mine exhaust does raise two important issues, though:

- Blasting re-entry times can be increased. However, Canadian mines have not generally found this to be a significant issue as:
    - development blasting fumes returning to the ramp usually mix automatically with much larger quantities of "fresh" air already travelling on the ramp;
    - production blasting fumes are not usually consequential as the mine is usually evacuated during production blasts
- The wind speed up-ramp cannot be too close to the up-ramp speed of a loaded truck or the truck may overheat and/or become shrouded in fumes. However, nor can the ramp wind speed be too high or too low as this results in other problems.

Despite these disadvantages, the merits of this system probably warrant its adoption in a number of favourable circumstances in Australia.

Conveyors replacing shafts

There may be a trend developing towards the use of conveyors for ore transport to surface for high-production mines rather than trucks. An underground-to-surface conveyor has certainly been implemented at Ridgeway mine. Conveyors from the underground to the surface have several ventilation issues that must be carefully addressed. The most significant is that the conveyor is potentially a serious fire hazard. The authors prefers the concept of a "neutral roadway" for the conveyor, so that the conveyor is in an intake but the intake leads directly into an exhaust, i.e. the conveyor roadway has its own supply of fresh air which is not then used as an intake for any other area in the mine besides itself; it basically becomes its own self-contained ventilation circuit.

Series versus parallel district ventilation

In the past, most Australian mines had an exhaust on each working level. Fresh air came from the ramp (or the intake shaft), was used on the level, and was then discharged into that level’s exhaust. However, the combination of the drive to lower costs and, in some cases, low ore tonnes per vertical metre, has meant that an increasing number of mines do not provide an exhaust on each level (in some cases, no exhaust is provided on any level except at the bottom of the mine). This results in the ramp becoming a “dirty intake” (even dirtier than just due to trucking) as the “exhaust” from the workings on one level returns to the ramp and becomes the “intake” for the next level.

Remote Load-Haul-Dump equipment

The introduction of remote-controlled LHDs has allowed mine planners to dispense with trough (“V”) undercuts at the bottom of stopes, with most stopes now having flat bottoms. In addition, the brow in the drawpoint on these stopes can be mucked opened without putting the operator in danger by the use of the remote facility on the LHD. As a consequence of these developments, drawpoint brows are now often open for a considerable period of the stope’s life. An open brow usually leads to short-circuiting between levels or between nearby open drawpoints with significant adverse impacts on the ventilation system. In addition, remote LHDs have actually led to the development of ore extraction methods that would not have been technically or economically practical in the past, such as longitudinal bench (or panel) or AVOCA stoping, which may involve permanently open brows.

Despite the benefits of these new techniques and the new technology, it is important for both planners and operators to realise that stope ventilation must be under control at all times or the products of the blasting, filling or the ore extraction and handling processes (gases, fumes, dust) will be at unnecessarily high levels. Sufficient top exhaust is essential on all stopes to ensure they are under negative pressure and therefore incast during all operations, so as to avoid dust and other contaminants produced within the stope escaping from the stope and entering the general mine ventilation air.

Fresh air bases versus fire refuge chambers

In the past, most mines established fresh air bases at the location where the working levels connected to the intake shafts. The lack of security in a fresh air system where the surface ramp is the sole intake has resulted in a trend towards refuge chambers which are frequently second-hand shipping containers. However, there is no Australian standard for these chambers and many mines are, in effect, operating with “coffins” rather than refuge chambers. Even the purpose-built “state of the art” chambers are still mechanical devices that depend on being properly maintained and, even if maintained, remain subject to failure during a real emergency. Underground fresh air bases with a blowing surface fan are simple and very effective and refuge chambers should never be considered to be as low-risk as a fresh air base.

An Australian standard should be developed for refuge chambers (in much the same way that there are Australian standards for the use of electrical apparatus in coal mines, or the use of diesel engines or explosives in coal mines). In the interim, the industry should develop and adopt a Code of Practice for egress and entrapment, including specifications for fresh air bases, and refuge chambers (Brake, 1999 and Brake and Bates, 1999)

Self versus aided rescue, fitness levels of the workforce, familiarity with ladders

Historically, if a mine emergency occurred, it was considered good practice to use mine rescue teams to find and then rescue workers after an emergency. Whilst this is still true to some extent, the duty of care now enshrined in legislation and in society itself makes it difficult to risk one person’s life to possibly save another person. The trend is therefore away from “aided” rescue to “self” rescue. The effects of this have not yet been fully understood by mine planners and operators, especially in hardrock operations. A further issue is the relatively low fitness levels of the modern workforce. In the past, it was normal for workers to routinely travel through the mine using ladder ways. However, the dramatic growth in both obesity and low fitness levels means that many workers today would be unable to climb any distance on ladders. This impacts on egress strategy (the mine still needs to provide for safe egress even for relatively unfit workers) and ultimately on ventilation design. Our opinion is that ladderways should be principally seen today as alternate routes for a mine rescue team to move around the mine and not for mine workers to be escaping. This is particularly true in the deeper mines where the ladders are much longer.

Diesel particulate matter

Diesel particular matter or DPM (very fine carbon particles produced in the diesel exhausts) are now considered by the International Agency for Research on Cancer (IARC) and the American Conference of Government Industrial Hygienists (ACGIH) as a carcinogen in animals and suspected carcinogen in humans. North America and Europe are spending large sums of money reducing DPM exposures. Coal mines in Australia (which have relatively low DPM exposures compared to many hardrock mines) are also spending considerable funds on reducing DPM exposures. The lessons of asbestos in the 1960s have some relevance. Australian hardrock miners are generally now well behind the DPM control measures considered to be good practice in many overseas jurisdictions and this could impact on health and safety and even increase exposure to litigation in the future.

Underground mines beneath open pits

There are an increasing number of underground mines being developed beneath open pits. A variety of problems have been encountered, including recirculation from the mine exhausts back into the mine intakes due to proximity issues or local ventilation effects induced by the open pit geometry, contamination from active open cut operations into the underground intakes and egress and entrapment issues. More care is required in some operations about the interactions between open pits and the underground mines beneath them.

Short mine life

The short mine life of many operations in Australia has driven project economics towards minimising up-front capital costs, even if this results in higher operating costs. When combined with the trend away from prescriptive legislation, this has resulted in some operators taking short-cuts and falling below industry good practice. The use of the surface ramp as a dirty intake (see above) is considered by these authors as one of these poor practices.

The cost of capital (driven by expected investor returns on the stock market) is also much higher than it was 30 or more years ago. Thus the discount rate on future cash flows is higher (mine owners must get their money back more quickly).

Ventilation is frequently seen as a cost and not as part of the mining process that adds value to the business. This leads to intense pressure to reduce ventilation costs. However, mine workers often see money spent on ventilation as money well spent and a key factor in their own health and safety and their enjoyment on the job.

Fly-in, Fly-out (FIFO)

Even mines that do have a ventilation officer may not always have access to that person. This is often the case with fly-in, fly-out (FIFO) operations. Some staff positions in FIFO operations are considered to be critical, so that when one person is off site, their counterpart is on site (this arrangement is sometimes referred to as a “back to back” roster). This would include surveyors, geologists and others associated with the production process. However, ventilation staff in hardrock operations are often considered to be non-critical, so that when the ventilation officer is “away”, there is no-one available to provide ventilation guidance. This has particular significance when it comes to emergency situations such as fires. Aware of this problem, some FIFO operations in Australia have re-written their emergency preparedness procedures so that the ventilation officer does not have any formal role in the event of an underground fire, as there is not always a ventilation officer on site. In the authors’ opinion, this is a significant flaw and a retrograde step. The reality is that no-one knows the mine ventilation system as well as the site ventilation officer.

Human Resource management impacts on technical personnel

The pressures on mining companies to cut costs have generally been relentless. This, along with the increased proportion of mines with short lives and the rationalising of ownership has led to a loss of employment security generally.

This loss of security along with the rigours of fly in-fly out operation means that many engineers plan to leave the industry by the time they are about 40 years old, departing from the industry at a relatively early age and taking their accumulated knowledge, skills and experience with them.

The churning (movement of individuals from one company to the next) has led to few engineers wanting to invest the time and effort into developing technical skills that may result in them being seen to be so specialised that they are among the first to be retrenched in the event of a change in corporate emphasis. They see that being multiskilled (i.e. being a generalist rather than a specialist) makes them more redundancy-proof. Therefore there is an often an unwillingness from the individual to develop a specialisation in ventilation.

In addition, it takes years of exposure to ventilation issues to develop an experienced and competent ventilation engineer. This process is not easily nurtured when the engineer must be regularly moving between companies due to lay-offs and takeovers. Therefore even if an engineer does want to pursue ventilation as a career, churning tends to selectively work against his (or her) ability to develop and then retain his skills.

The lower emphasis on ventilation (in hardrock mines) has, in part, led to the relatively fast rotation of young mining engineers through the role of ventilation officer or engineer. This is resulting in a very wide variation in technical competence within mines in Australia. In addition, many mines assume that the ventilation knowledge that a young engineer obtains as a University undergraduate is sufficient for him to take on the role of the mine ventilation officer. This is rarely the case; in effect, the engineer is thrown into the job with little on-site or off-site support and left to “sink or swim”.

The churning of the workforce and multiple employers over a working career can also result in gaps in the knowledge or experience of underground workers and can also result in a situation where a miner develops an occupational illness, such as pneumoconiosis, but the relative contribution of the various mines that he/she has worked at can be difficult to establish.

Community expectations regarding occupational health and safety

Increasingly, investigators into workplace accidents or incidents are examining workplace environmental factors and their impact on the accident. For example, a welder might be electrocuted and the prima facie finding is that he took a shortcut and did not comply with the standard operating procedure to which he was trained. However, further investigation may find that the workplace temperatures were excessive, so that the welder just wanted to get the job done, which contributed to taking the shortcut and the resulting fatality.

Some States have considered introducing industrial manslaughter style of legislation, which would allow managers (or any other responsible person) whose negligence resulted in the death of an employee to be prosecuted and jailed. Technical areas such as ventilation or rock mechanics, which clearly involve judgement calls at times, and where decisions can sometimes be counter-intuitive, are therefore now considered to have higher risk profiles.

It is therefore very likely that workplace environmental conditions will need to improve over the next 20 years and that the competence level of ventilation staff in hardrock operations will need to improve and become more consistent.

Deeper operations

Many large, near-surface orebodies have been exhausted. Frequently, mines are moving deeper, which often means conditions are hotter. Furthermore the large amount of diesel equipment and intense extraction methods which has made modern mines so productive has also introduced large quantities of heat. The large equipment, including large auxiliary fans, has also created more significant noise problems underground.

In more recent years, the introduction of reliable and effective air-conditioned operator cabins has led to a dramatic improvement in the workplace environment for many mobile equipment operators and some other type of equipment operators (e.g. jumbos, production drill rigs). However, air-conditioned cabins can be a trap for workers and managers alike in that the cabin may protect the driver from heat but will not provide protection from gas. Situations are starting to occur where LHD operators are entering a recently blasted face and may commence mucking even though gas levels may be excessive.

The importance of ventilation standards, a ventilation plan and competent site ventilation staff

In our opinion, many Australian mines no longer conduct sufficient forward thinking regarding the mine ventilation system but simply keep extending the mine and the ventilation system until it is manifestly inadequate. This failure to plan is at least in part made possible by the absence of ventilation standards in many mining companies. If firm standards existed, then planning and auditing would be required to ensure these can be maintained.

Consider the following quotation from the official enquiry into the terrible Westray coal mine disaster in Canada that killed 26 miners on 9 May 1992 (Richard, 1997):

> "Ventilation planning for Westray: Ventilation planning for the Westray mine did not address the requirements for a comprehensive system of fresh-air circulation and methane removal. The plan on which the ventilation was based was merely a brief outline in a feasibility study. A comprehensive engineering study by competent ventilation experts was not completed and documented before approvals were requested…"

Past safety performance or reputation is no guarantee that conditions are properly managed or the risks are acceptably low. The Westray mine was awarded the John T Ryan Award as Canada's safest mine barely one month before the explosion (Anon, 1998). There were numerous important recommendations that arose from the Westray enquiry. Two of most important in terms of ventilation were the need to have a comprehensive ventilation plan, and the need to retain the services of a competent ventilation engineer. Some of the larger mining companies operating in Australia now have their own company-wide ventilation standards and also require a ventilation officer to be appointed on each mine site. These are important first steps towards providing a consistently safe and healthy workplace in terms of the air quality across all their operations. However, training of site ventilation engineers/officers to a national competency standard is also an essential step towards improving the design and operation of the ventilation systems in Australia. On-the-job training tends to create individuals that are competent only in the issues at their operation, if that. When they move elsewhere, there is a danger that they will think that all mines are like the one where they learned their skills. In our opinion, the position of ventilation officer in hardrock mines in all Australian jurisdictions should be a statutory appointment with competency to a nationally accredited standard as is the case in coal mines.

RECOMMENDATIONS

The authors believe the following recommendations need to be considered by the Australian underground mining profession as a whole:

- Every mine needs to have a mine ventilation standard which addresses all the ventilation hazards and this standard needs to be regularly reviewed and audited.
- The position of mine ventilation officer is critical to the safety and health of underground workers and should be a statutory appointment in all jurisdictions.

- A national competency standard for hardrock mine ventilation officers, developed by the industry itself, already exists. However, *not one person* to this point in time has been trained to this standard. The standard should be reviewed and become the de facto or prescribed competency standard for statutory appointments and adopted as a voluntary code by all mine operators.
- Airflow requirements for hardrock operations will become higher due to the heat, gas and DPM output of bigger diesel engines. This will be accelerated as emissions standards become tighter (especially DPM). New technology such as fuel cells holds some promise for removing big diesel engines from underground, but is unlikely to see substantial adoption by the industry in the next five years. Ventilation costs will become more expensive in the medium term as diesel engines become larger and more mines adopt refrigeration.
- “Ventilation on demand” will become practical and economic. This will have major impacts on mine planning and operations.
- The use of a single surface ramp as an intake and a single exhaust shaft (with a surface exhausting fan) is a poor ventilation strategy and should in many cases be phased out. It is doubtful if such an arrangement meets the standard for duty of care, or bringing the risk as low as reasonably achievable. Better solutions are to adopt separate intake and exhaust shafts (with or without a surface ramp) with a blowing fan on the intake and the ladderway in the intake (along with the refrigeration plant, if required), or to use the sole shaft as an intake (with a blowing fan and ladderway) and the surface ramp as an exhaust. Care will be required to ensure blasting re-entry times are monitored, gas levels are not exceeded and uphill ramp wind speeds do not conflict with uphill trucking speeds.
- Where conveyors are used to move ore out of the mine, the conveyor roadway should in most cases be a neutral intake, i.e. fed with its own supply of fresh air and provided with its own exhaust.
- The use of series ventilation in the main ramp intake (where the exhaust from a working level is reinjected into the main ramp and then used as the intake for a subsequent level) should be avoided wherever practicable.

- Mine design and operating practices should ensure that production ventilation is under control at all times so that the products of the blasting, filling, extraction and other mine processes are not at unnecessarily high levels.
- An Australian standard should be developed for refuge chambers (in much the same way that there are Australian standards for the use of electrical apparatus in coal mines or the use of diesel engines or explosives in coal mines). In the interim, the industry should develop and adopt a Code of Practice for egress and entrapment including specifications for fresh air bases and refuge chambers.
- The philosophy of ladderways and the role of mine rescue should be reviewed in the light of changing community and legislation standards relating to rescue activities.
- A Code of Practice should be developed regarding the measurement of diesel particulates in the workplace and acceptable exposure levels.

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