THE GROWING USE OF HAZARDOUS PRIMARY VENTILATION SYSTEMS IN HARDROCK MINES

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ABSTRACT

Fire has historically being the biggest single cause of underground hardrock mining disasters and traditional primary ventilation systems and practices were developed, over a long time and after many such disasters and subsequent inquiries, to provide the safest practicable conditions for miners in the event of a major fire. The reduction in the use of timber underground and the introduction of sophisticated fire mitigation systems in modern diesel vehicles has resulted in a significant reduction in major fires. However, major fires still occur and most risk assessments still identify a major fire as a very serious threat. This paper discusses some recent trends towards intrinsically risky mine ventilation design practices especially the use of the second means of egress as part of the exhaust circuit, and the use of the truck haulage ramps as the primary intake. It identifies the factors that have led to these changes and offers some alternative designs. It proposes a classification system and hierarchy or ranking of primary ventilation methods and a set of progressive criteria that should be applied to all ventilation designs to determine their fitness for purpose.

KEYWORDS: SERIES VENTILATION, ESCAPE, EGRESS, FIRE, DESIGN

1. BACKGROUND

Given that serious fires in underground hardrock mines are rare and fatalities from disasters are even rarer, how serious is the risk from these changes?

- The history of hardrock mine disasters (NIOSH, undated) shows that fires and explosions are the cause of more than 90% of all disasters (disaster being defined as five or more fatalities from a single event). Disasters such as major fires are low probability, high consequence incidents. The reality is that an out-of-control fire on a large underground diesel machine is still a credible threat in almost every underground hardrock mine.
- Lowndes et al (2005) comment as follows:

  Underground fires represent a constant threat to the safety of underground personnel. Miners in the immediate vicinity may face intense heat, blinding smoke, toxic fumes, fall of ground and other direct effects of a fire. However, the vast majority of victims never actually see the fire, and are overcome either by deadly fumes in the ventilating current or by asphyxiation. The mine ventilation system, which maintains a sustainable atmosphere to the working places, can transport products of combustion with equal efficiency. Miners who are remotely situated from a fire may be forced to evacuate considerable distances, through dense smoke and fumes, or even become cut-off from escape. Additionally, miners may become confused by unfamiliar ventilation characteristics caused by fires.
- The recent (2006) incident at the Avebury mine development in Tasmania provides valuable lessons in this regard. A diesel truck travelling down the surface ramp rolled over on a corner and caught on fire. The engine fire suppression system failed to put the fire out. The fire could also not be extinguished by the operator using handheld fire extinguishers. The downwind workers took refuge in a self-contained refuge chamber until they were safely rescued some ten hours later. Avebury demonstrates that out-of-control fires on trucks in ramps can still occur today and that the fact that no-one can get past a burning truck is a far more serious issue when the mine has only one practical means of egress (the ramp).

Any serious injury or fatality in any mine is a cause for great distress. However, a serious mine fire, if accompanied by multiple fatalities, is not only devastating on families and the community, but in many cases results in the closure of the mine which causes further devastation to the local community, and in some cases, results in termination of the mine operator as an on-going concern.

2. INTRODUCTION

2.1 One pass ventilation system with secure, isolated fresh air to each working district

Forty years ago, surface ramps into metalliferous mines were virtually unknown. The major mines had vertical hoisting shafts (invariably in fresh air to protect shaft equipment and also for fire security) and at least one surface exhaust shaft. The shafts did not have "dog legs" (horizontal off-sets) in them due to their intended purpose (hoisting) and/or method of construction (vertical sinking). Larger mines requiring higher airflows had a number of unequipped surface intake and exhaust shafts due to the limited air-carrying capacity of a fully equipped hoisting shaft. Very large mines sometimes had surface fans on both intake and exhaust shafts to allow easier balancing and more targeted delivery of air underground. These ventilation shafts were connected to every working level with intermediate sub-levels ventilated by smaller internal air raises connecting between levels. Once established, each level therefore had an independent supply of fresh air and an independent exhaust. A fire on one level would not affect any other level, unless that fire was in the hoisting shaft. Very strict precautions were taken in the hoisting shaft, including (in most cases) the use of concrete lining, steel furniture, steel fire doors on every shaft plat and strict "hot work" (steel cutting and welding) procedures. Underground equipment was electric or compressed air powered, producing no fumes or gases so that dust and/or strata gases were the main ventilation issues. Due to its critical role in transporting personnel, equipment and ore/waste, the hoisting shaft had to be commissioned prior to level development or production, so that "pre-production" or simultaneous production while main infrastructure was still being developed or constructed did not occur. The main risk of fire in such a mine was from the extensive use of timber for ground support, ore and fill passes, ventilation controls and other construction works. The most dangerous toxic product of combustion from a timber fire was carbon monoxide. In the event of a fire, workers were told to proceed to the nearest fresh airbase. They were also told to not enter smoke which meant more than one fresh air base had to be accessible via more than one "egress", i.e. provision of a second means of egress. Self-rescuers, if they were provided at all, were the filter type that removed CO only. This method of primary ventilation provides highly secure fresh air bases on each level and a secure primary and secondary means of egress via the main cage, the top of the skips and a ladderway in the hoisting or other dedicated shaft. Ladderways in vertical airways connected levels and workers were routinely using these for everyday activities. This style of primary ventilation could be described as a *one pass ventilation system with secure, isolated fresh air to each working district* and is shown in Figure 1. On a hierarchy of primary ventilation systems (Table 3), this was the most secure and robust. Variations on this theme included:

- Whether the intake had a surface fan pressuring it, or whether it downcasted under the influence of surface exhaust fans, underground blowing fans attached to itself, or underground exhaust fans elsewhere in the circuit
- Whether the intake was completely isolated from the rest of the mine or whether there was some low-risk shared connections, often in very low activity areas

The series style of ventilation was considered a major contributing factor to the fatality count in the Sunshine mine disaster in the USA in 1972. Most legislation in Australia required a one pass system "wherever practicable". For example, the Queensland legislation until 2001 stated that *"The workings of each level in every mine shall, where necessary, be ventilated by a separate split of air from the main intake into such level and after passing through those workings the air shall be led as directly as possible to the return airway"*; similarly, the current Western Australian regulations state: *"contaminated return air from any secondary ventilation circuit is, if practicable, exhausted directly to the primary return air exhaust system or, if that is not practicable, contamination of the primary intake air flow to work places which are downstream of any secondary ventilation circuit is minimized by directing the return air from that secondary circuit by the most immediate route to the primary return air exhaust system"*.

In addition, the Western Australian *Approved Guideline for Underground Metalliferous Mines* (1997) has the following comments:

> *A further major consideration with deep and extensive underground mines is the tendency to lean towards series ventilation circuits.*
>
> *The main problem with series, or parallel-series circuits is progressive contamination of the air by recirculation from secondary ventilation system returns, and the increased fire risk, in that the fumes and smoke from any fire in the intake or any upstream section of the mine will be carried into working sections downstream.*
>
> *In most cases, the system should be designed and scheduled to provide parallel paths from the primary fresh air intakes through operating areas*

to return airways connecting to exhaust rises and shafts.

In general terms the shorter and more direct the ventilation circuit through each working area, the better the system.

Maximum use of parallel paths will reduce the overall mine resistance for a given air flow, which in turn greatly reduces the power required and the operating cost. The essential proviso to this is that adequate volume flow through each working area is maintained to dilute dust and contaminants and ensure operator comfort

This approved guideline goes on to say:

It is axiomatic that close attention is paid to the location of intake airways to ensure that the potential for contamination of air drawn into the mine is minimised.

No activities generating dust and fumes should be allowed in the vicinity of the intake and all installations built of combustible materials or containing combustibles or inflammable materials must be located at a safe distance

On the same principle, care must be taken that no unprotected fire hazards are created by installations in or near primary intake airways underground.

Workshops in intake areas should have sprinkler type fire protection.

2.2 Internal ramp as neutral or semi-neutral intake

Two key events then occurred that have since transformed hardrock mine ventilation systems.

In the 1960s, diesel equipment and in particular diesel loaders (LHDs) were introduced to improve productivity. The problems with moving LHDs between levels and sub-levels (requiring the machine to be disassembled into pieces) and also the problems of refuelling LHDs (requiring steel fuel lines to be run into sub-levels from the levels), along with maintenance issues, caused operators to develop ramps between important levels and sub-levels. Initially these ramps merely replaced service raises and often were mined up or down off a main level only as far as the particular stoping operation required. They had a minor role in ventilation as each level still had its own intake and exhaust and the ramps were internal only, i.e. did not connect to surface. This style of connection is called a *neutral intake*, meaning that whilst the airway carried fresh air, the air is not then used elsewhere in the operation. Two variations of the ramp as neutral intake situation are shown in Figures 2 and 3. The bidirectional flow option (Figure 2) never introduces ramp air into the main workings; the unidirectional flow option (Figure 3) effectively discharges part of the ramp flow into the intake to some of the working levels. The bidirectional flow option was more secure but required a return air raise (RAR) connection near to the ramp along with some form of top exhaust connection from the ramp RAR to the surface exhaust shaft; the unidirectional flow option is somewhat less secure, but requires no ramp RAR connections and no top exhaust. Note that the ramp development process itself usually required an adjacent RAR, which was often used as a waste pass with a rail transport system at the bottom of the pass system.

With no trucking on the ramp (the ramp effectively being used as a replacement for a ladderway), the amount of flow required for the ramp was relatively small so that in both cases, ramp air was not part of the primary ventilation system.

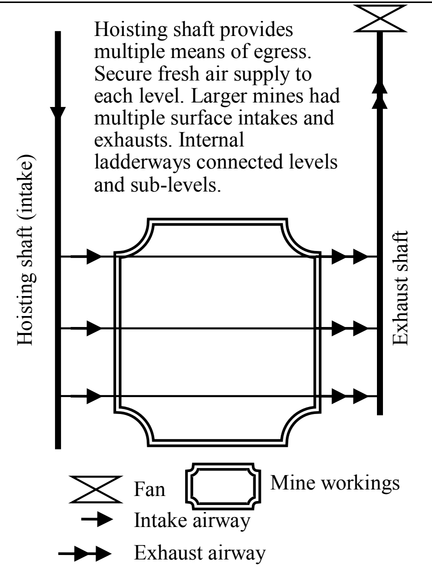

Figure 1 One pass ventilation system with secure fresh air supply to each working district

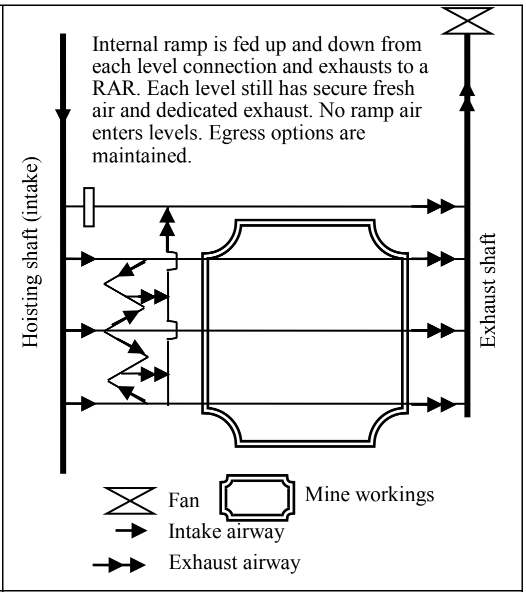

Figure 2 Internal ramp as neutral intake with bidirectional flow on ramp

Internal ramps reduced many problems associated with operating and maintaining large diesel equipment, but there was still the problem of having to dismantle the LHD into pieces to take it underground (and then reassemble it) and vice-versa when the machine needed a major overhaul or rebuild. In addition, there were increasing problems getting all the stores, fuel and other items required for a modern mine into and out of the underground operation.

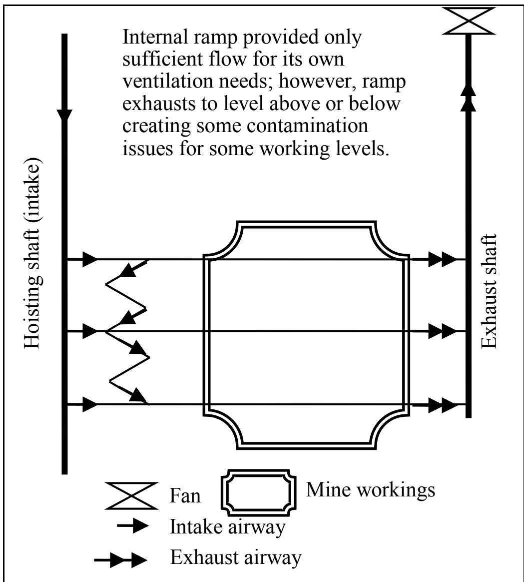

Figure 3 Internal ramp as semi-neutral intake with unidirectional flow on ramp

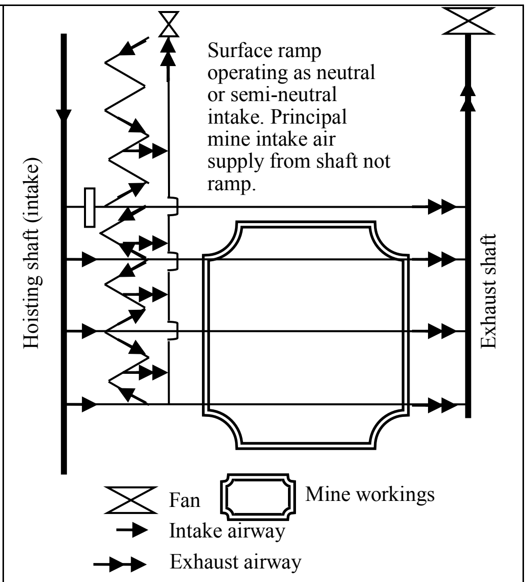

Figure 4 Surface ramp as neutral or semi-neutral intake and flowthrough ventilation on each level

2.3 Surface ramp as principal or sole mine intake

Then in about 1980, the price of gold increased dramatically and the new CIP and CIL technology made small surface low-grade gold resources economic for surface mining. As near-surface operations soon became exhausted, many developed into small underground mines. With limited life and shallow depth, the surface ramp typically became the mine intake with the single vertical "winze" connection (taken down in short legs to provide for the ramp development), also used for subsequent production.

At this point, the ventilation systems for the more traditional and newer mines started to diverge.

For the mines with hoisting shafts (Figure 4), the surface ramp usually continued to play a minor role in the primary ventilation system. Where it was installed, it was basically a service connection for diesel equipment. The shaft(s) remained the major service and ventilation arteries for the mine, but the surface ramp provided a means of getting larger equipment in and out of the mine without disassembly. It also reduced the pressure on shaft downtime and proved most useful for many other activities such as bringing premixed concrete, explosives, specialised vehicles and the like into the mine.

2.4 Surface ramp as principal or sole intake with exhaust on each level

However, for the smaller mines, the capital cost to prove up sufficient reserves (particularly given the nature of gold mineralisation) and then install a hoisting shaft was not economic. The mine was therefore designed for the ore to be mined and then trucked to surface, often using contractors. The surface ramp continued to develop by taking a series of short return air connections (RAR) down with each "leg" (loop) of the ramp (Figure 5).

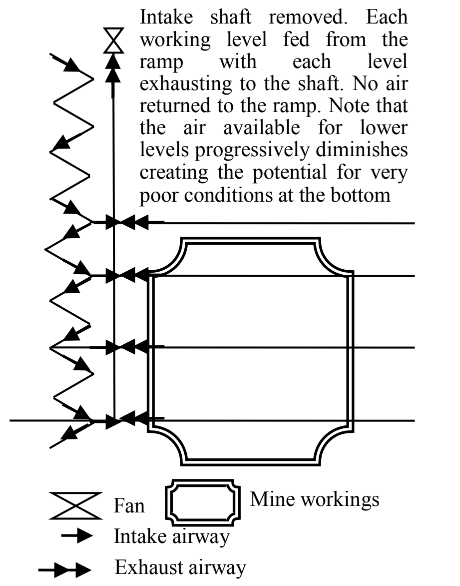

Figure 5 Surface ramp as principal or sole intake with exhaust on each level

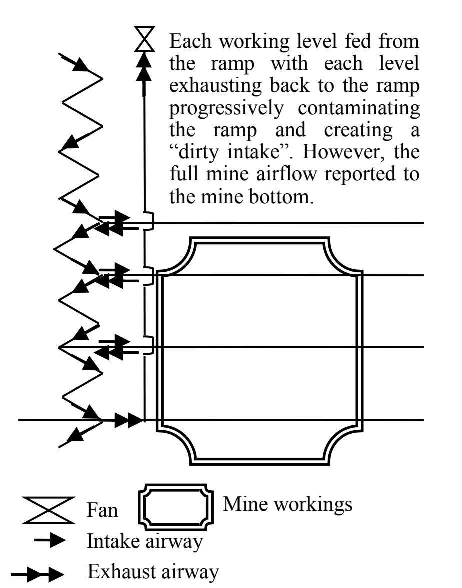

Figure 6 Surface ramp as principal or sole intake exhausting from each level back to ramp ("Series ventilation" or "Ramp as dirty intake")

Some mines with a small orebody and low tonnes per vertical metre, small diesel fleet, small workforce and short expected mine life, elected to use this ramp-development RAR (often mined at small size) as the *only* other surface ventilation connection, even when production started. This decision was also influenced by the fact that this style of mining was a "top down" approach, i.e. it was most economic to develop the ramp only down so far to a point where production could start to generate revenue. The main ramp was then progressively extended as the mine required production from deeper regions of the orebody.

2.5 Single pass ventilation system with a non-segregated shared intake

In most cases, operators initially took air off the ramp on each working level and then discharged the spent air into the RAR on that level using a *single pass ventilation system with a non-segregated shared intake*. Vitiated air was not returned to the ramp (Figure 5). The risk from a diesel truck fire on the ramp remained, but any fire, dust, fumes or POCs produced on a working level went directly into the return. The system lost any option of providing fresh air bases on each level. The surface ramp became the primary means of egress. Partly in recognition of the problems of this, the industry did adopt engine fire suppression systems, self-contained self-rescuers and, more recently, refuge chambers as part of a risk control strategy for this style of ventilation. However, in the safety “hierarchy of controls”, the strong control of a highly secure intake air design and fresh air bases on each working level had been replaced by intrinsically weaker controls. Nevertheless, in the early stages, the number of mines practicing this system was small; the number of workers in these mines was also small, and the mines were relatively shallow, so that little concern seemed to be expressed about this poor design either by the industry or by the regulators.

Note that in this system, as fresh air is taken into the RAR system from the ramp on each upper level, there is progressively less air remaining in the ramp to feed the lower levels. As these lower levels often produce the most contaminants due to heavy amounts of development and production activities in this region and the continual exposure of fresh, hot rock surfaces, this means that the quality of the air entering the RAR system at the mine bottom is often very poor. In a number of circumstances, we have found that the contaminant levels in the bottom working levels of a mine using this ventilation system are worse than the contaminant levels in the exhaust (RAR) system as the RAR system combines the very dirty air from the bottom with relatively cleaner air from upper levels!

2.6 Series “dirty intake” ramp as primary intake

As these small mines became larger, they continued to want to operate this compromise primary ventilation system. In fact, a whole generation of mining engineers has grown up with this system. However, this method faced one other serious problem. With the ramp as the only intake, wind speeds were limited to about 6 m/s (to avoid dust problem) and with typical ramp sizes of 25 m^2 to 30 m^2, the total mine airflow was limited to about 150 to 180 m^3/s. If the ramp face and one or two levels were under development, and production was occurring from another one or two levels, there was simply *insufficient air for a “single pass” ventilation system*. By default, fans were hung in the ramp above each working level and air was ducted from the ramp into the workings on that level. The vitiated air from that level was left to return to the ramp before progressing down the ramp to the level below and become the “intake” for that level (Figure 6). The *series* or cascading ventilation system repeated on each level leaving the ramp as a “dirty intake”. This generally improved the conditions at the ramp bottom due to the higher flows reaching the bottom, but at the expense of an even less secure ventilation system (for fire and egress) and poorer working conditions on upper levels due to the series ventilation.

It is important to note that recirculation or air is banned under most jurisdictions. However, series ventilation can produce a build-up of contaminants that is just as serious, and in some cases worse, than recirculation.

A further problem with this style of ventilation is the dramatic increase in mine resistance with depth, compared to the more traditional methods. This increase is not linear but rather is exponential and often catches the mine operator unawares and forces the mine into either a major ventilation upgrade, early mine closure, an unwanted reduction in production rate, or accepting poor ventilation conditions for workers. With time, not only did these mines become larger but they also became deeper. The increasing depth introduced other problems. Firstly, the number of trucks to maintain a production rate increased due to the increasing tonne-km of the return haul. The amount of diesel fuel burnt on the ramp along with the amount of diesel heat, gases and fumes all increased commensurately. The truck travel time on the ramp increased, increasing the exposure of the operation to a truck fire on the ramp. Often the ramp is so busy that there is insufficient time available for adequate road surface maintenance (grader time) and often the road is not sufficiently watered to prevent dust, due to problems with wheel slippage on the trucks. The net result is that dry, dusty roads are tolerated.

Air conditioned cabins were introduced onto many items of mobile plant to reduce the heat problem; however, air conditioned cabins do not remove diesel gases or fumes, may have little effect on dust exposures, and certainly would not protect from products of combustion.

A further problem introduced by this form of series ventilation and the loss of any exhaust on the working levels was the loss of top exhausts on active stopes. With the ability of remotely operated LHDs to load all ore from the flat bottom of a stope, there was no longer any need for trough undercuts. The “brows” at the stope bottom were no longer choke fed with ore, but kept wide open, creating major ventilation short-circuits. Consider the situation shown in Figure 7. A fan or fans is being used to ventilate the ramp face extension at the mine bottom and the bottom working level (Z). The return air from these activities reports to the mine bottom RAR connection. In Figure 8, a stope has been holed through between the two bottom working levels (a common occurrence). When the stope brow on Level Z comes open, a short circuit (parallel path to the ramp) is introduced between Levels Y and Z. The air circuit through the stope is much lower resistance than the route through the ramp; there is now insufficient airflow for trucks on the ramp. Contaminant levels in the ramp between these two levels increases, often creating a murky “dead spot”. The development fans continue to pull the same airflow, but there is now insufficient air travelling down the ramp in this region to ensure the fans do not recirculate. As a result, the fans do recirculate further increasing the contaminant levels being fed to the active workplaces. This is not an uncommon occurrence and can occur on levels above the bottom level as well. To avoid the recirculation, some operators will turn one fan off and put the LHD (with air-conditioned cabin) in this unventilated heading. However, this is not a safe solution.

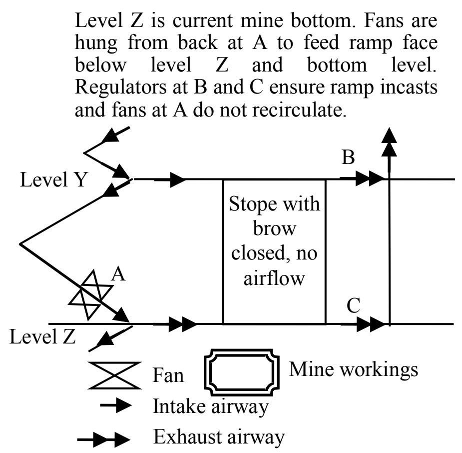

Figure 7 Bottom levels of mine with no short circuit

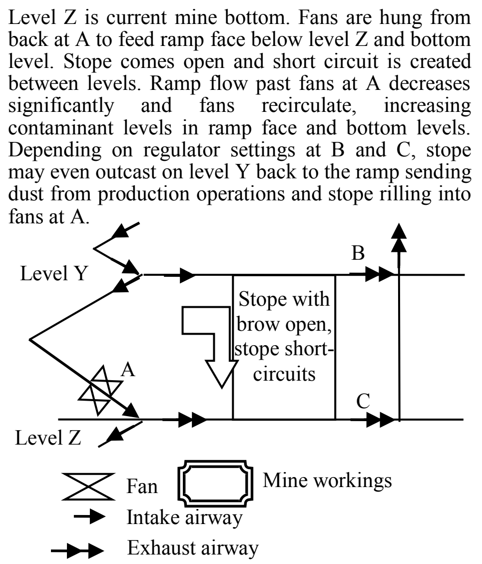

Figure 8 Bottom levels of mine with short circuit

Finally, the use of the surface ramp as a critical “series” part of the primary ventilation system is also having a further detrimental impact on ventilation systems. Because a ramp has limited carrying capacity (150 to 180 m^3/s at 6 m/s for intake travelways), incorporating the ramp into the primary ventilation system is putting a “cap” on total mine airflow rates. Compared to a shaft, ramps are expensive to mine as, at a gradient of typically 1 in 7, they require 7 metres of development for every vertical metre. There are many mines that need more than this airflow, but are caught between the desire to minimise the cross-sectional area of the ramp, and the need for sufficient airflow for a well-ventilated operation.

3. SIZE OF DIESEL ENGINES

Aggravating this problem is the dramatic increase in size of modern diesel engines. In a recent example, a mine operator wanted to develop about 1000 m from the nearest ventilation through-connection using AD55 600 kW trucks and R2900 321 kW loaders. After about 600 m, the heading split into two with each split proceeding about a further 400 m. When told that each split would require about 46 m^3/s at the face, and that with leakage, the airflow at the fans for both headings could be up to 120 m^3/s, the operator was horrified. However, all too often, inexperienced or incompetent mine operators are purchasing larger and more productive diesel equipment without thinking through the ventilation consequences.

4. ABNORMAL CONDITIONS AND ESCAPEWAYS

A crucial point about the design of primary ventilation systems is that they must not only meet *normal* operating conditions but also *abnormal* conditions, such as in the event of a fire or power outage or other credible threats. All too often, fire amelioration and the issues of egress and entrapment are given insufficient consideration as key design factors in the selection of the primary ventilation system.

In this regard, a comment is warranted about the use of ladderways as second means of egress. Studies have found that mine workers today are relatively unfit, especially compared to the miner of 20 or more years ago. Many underground truck drivers today would be incapable of climbing the fire escape staircase in a 40 storey (floor) building from bottom to top. If it was a ladderway rather than a staircase, then it would certainly be impossible for many. However, a 40 storey building is only about 120 m high, i.e. a very shallow mining operation. In this author's opinion, it is unrealistic and unreasonable to consider a ladderway in an underground metal mine to be a second means of egress. Two alternative and more valid views are:

- A ladderway in the surface fresh air raise (FAR) provides a means for mine rescue teams to safely get underground in fresh air, to establish forward fresh air bases, and to effect search and/or rescue operations, or
- The surface FAR provides a means to wind personnel out of (or into) the mine using either a dedicated emergency winder or a portable winder brought to site under a pre-established emergency egress plan.

It is not the intention of this author to argue against engine fire suppression systems, self-contained self-rescuers (SCSRs), refuge chambers or any of the other fire amelioration controls introduced into the industry in the past 20 years or more. The author has been a strong advocate of these controls for many years (Brake, 1999). In particular, there is a strong case for the judicious and appropriate placement of refuge chambers in hardrock mines, and in some cases in coal mines as well. However, do these controls allow the risk from fire to be both at an "acceptable level" and "as low as reasonably achievable"? Recent audits of "high tech" refuge chambers in Western Australia found many had serious deficiencies due to poor maintenance (Anon, 2008). In addition, most mines have no credible way of ensuring the number of persons in any area does not exceed the capacity of available refuge chambers.

4.1 In case of fire, use lift (elevator)

In some Australian mines, the second means of egress has became a ladderway installed in the RAR. This is a major retrograde step from previous designs. Not only was the ramp no longer a neutral intake so that a fire in the ramp would pollute all working levels below that location, but the second means of egress was now in the main mine exhaust. Any ladderway in this system would be contaminated by the products of combustion. This style of second means of egress could effectively be called the *"In case of fire, use lift"*. However, a second flawed approach to egress ladderways is also seen now in Australia, where the escape ladderway is developed off the ramp system. Unfortunately, airflow in the ladderway is *not independent of the ramp ventilation*. In many cases, the ladderway swaps from one side of the ramp to another, or from side to side in a crosscut off the ramp. Clearly a fire in the ramp will introduce toxic fumes into the egress. This is similar to having the fire escape in a multi-storey building swapping from one side of the building to another, with those needing to escape being forced to leave one fire escape and travel across the building to another escape.

4.2 Rescue-ability

This author has been told by some senior managers that a fire in an upper area of a mine will simply render workers in the deeper regions "un-rescueable". For example, that mines rescue would not be able to get past a truck on fire in the primary means of egress, and would be incapable of safely getting to the required depth via the secondary means of egress. This is an unacceptable situation. Management on surface must be able to know what workers are safe and which are still unaccounted for. Even for workers that are safe, if the entrapment is likely to be prolonged, some may need urgent medical support (e.g. due to CO poisoning) and there could be workers with diabetes or hypertension or other medical conditions that need medication.

The purpose of having two means of egress is that if one is taken out by fire or rockfall or other event, workers who have reached a formal refuge station or fresh air base, can still be reached and rescued via the other egress. No mining area should ever be established where workers are beyond rescue.

It is clear from the above analysis that a series of changes has been introduced over some time into primary ventilation practices in Australia, starting from a minor base quite some years ago. However, what was at the time an isolated occurrence has become a mainstream primary ventilation system. The net effect is that primary ventilation systems are not as robust as they were previously. The situation has been aggravated by the short tenure of many mining staff at operating sites, which promotes a short-term view of systems design. There is usually no "custodian" who has longer-term ownership of the mine ventilation system on site.

5. STANDARDS FOR VENTILATION DESIGN

In this author's opinion, meeting the minimum legal requirements for mine ventilation design by itself is insufficient. For professional engineers, a succession of criteria should be applied to determine if a mine ventilation design is appropriate for any particular circumstance.

- *Legal requirement:* Does the design meet statutory mining regulations and binding local or international standards?
- *Approved standards or guidelines*: If there are no statutory approved standards/ guidelines and the design will be exposed to a particular hazard, then approved standards from other competent authorities (e.g. other provinces or countries) that address this hazard should be investigated. For example, another country may have developed an "Approved standard" or "Code of practice" for managing this hazard and duty of care requires this information to be at least considered within the design process. Approved standards or codes from other legal regimes may not be legally binding, but any alternate design should at least achieve a similarly low risk profile.
- *Company Ventilation and other Management Plans/ Standards*: There should be a Ventilation Management Plan for every mining operation (see later). The design proposed in the study must be consistent with this Plan.
- *Good Practice*: Any ventilation design can meet "ordinary" practice or "poor" practice. However, duty of care requires designs to meet "good" practice and, in some cases (e.g. where the risk is high), "best" practice. The fact that "someone else is going it that way" is not sufficient justification to go out and do it that way. For example, one province may accept 0.04 m3/s fresh airflow per rated kW for diesel engines, but this is below international norms and "good practice".
- *Acceptable level of risk*: Based on a formal, written risk assessment, are all the risks in the design at an acceptable level?
- *ALARA (as low as reasonably achievable)*: Even if the risk is acceptable, is there any way to reduce it further that is reasonably achievable? If so, the risk should be further reduced to this level. For example, the legislated 8-hour TWA for carbon monoxide may be 25 ppm, which is therefore an "acceptable" level of risk, however, most mines can achieve much better results than this, typically under 10 ppm, so this is the level that should be "reasonably achievable" and therefore in the design. Note that demonstrating ALARA means at least two options must be considered.

  Commenting particularly on what is an "acceptable level of risk", in Australia (e.g. Queensland), the Mining and Quarrying Safety and Health Act 1999 states under Part 2 "Basic Concepts" and Division 1 "Control and Management of Risk":

  What is an acceptable level of risk

  Reg 26.(1) For risk to a person from operations to be at an "acceptable level", the operations must be carried out so that the level of risk from the operations is: (a) within acceptable limits; and (b) as low as reasonably achievable.

6. WHERE TO FROM HERE?

6.1 Revise the legislation

One option is for the industry and regulators to simply deem that the risk from the various forms of series primary ventilation is now "acceptable". However, the "in case of fire, use lift" strategy would not be acceptable in the building design for any commercial building such as a hotel or office building. Is this style of ventilation then the best that can be "reasonably achieved" for a modern underground mine?

6.2 Increase the controls

Where series ventilation is practiced, it is this author's option that at least the following additional controls are required over and above those already in common use. These four controls are particularly identified as it is this author's opinion that these are lacking in many current designs.

- A second means of egress with its own independent secure supply of fresh air, preferably pressurised above any adjacent "dirty" intakes, so leakage is out of the second means of egress, and not into it. This second egress should have no risky combustion sources in it.
- Robust, secure fresh air bases or refuge chambers. These need to be sized and located so that they are sufficiently close to all working places.
- Self-contained self-rescuers sized to match the rest of the egress strategy. They must be carried by all persons underground at all times. Egress procedures need to be re-written and miners re-trained for escape through smoke as operating a series-ventilation system will inevitably result in some miners being required to escape through smoke.
- Early combustion warning and personnel notification systems, including judicious use of real-time carbon monoxide monitors in intake and exhaust circuits, and systems such as the PED.

This is certainly *not* an exhaustive list and must form part of an integrated strategy developed after bench-marking good practice and suitable risk assessments applicable to that site.

6.3 Review role of main ramp in primary ventilation system

Ideally, every working level would have its own intake air direct from surface and would exhaust its own pollutants directly to surface, keeping the working levels independent of one another, and also ensuring that a fire in the ramp does not affect any working level. However, where the main surface ramp must be used as part of the primary ventilation system, an option that has failed to be taken up by Australian miners is to "reverse" the ventilation and use the surface ramp as the main exhaust (Figure 9).

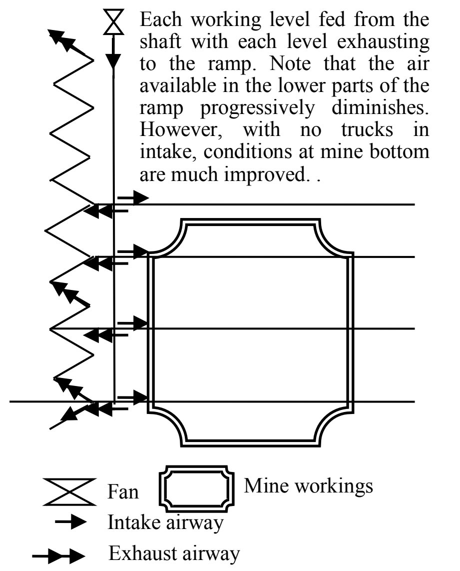

Figure 9 One pass ventilation system with ramp as exhaust and shaft as intake

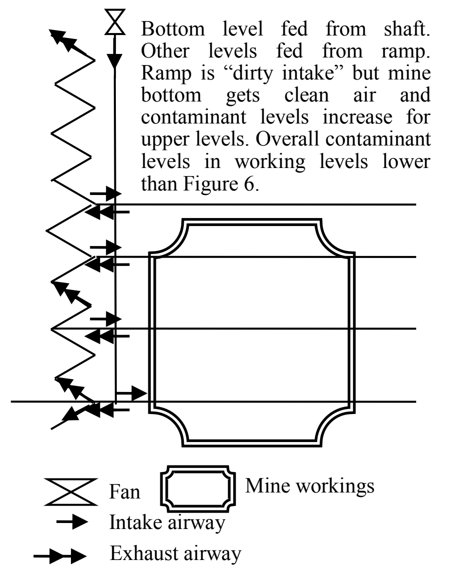

Figure 10 Series ventilation system with ramp as exhaust and shaft as intake

This system has a number of advantages over the use of the surface ramp as the dirty intake.

- The intake airway is now much shorter. It has no diesel equipment operating in it. It has no need for water to be sprayed into it for dust suppression on roads. Now only is it shorter, but the 6 m/s wind speed limit no longer applies. Therefore:
    - Temperature increase is much lower. A single 350 kW diesel truck will give off about 1 MW of heat when travelling loaded up a ramp. These heat loads are removed from the intake.
    - Gases, fumes and dust production in the intake are reduced to nil (assuming no strata gases)
    - Higher overall mine airflows are possible because the ramp, now being the mine exhaust, can sustain wind speeds of probably at least 8 m/s.
- The "best" intake air is sent directly to the very lowest point in the mine, which is usually the most difficult location to ventilation and normally suffers the worst workplace conditions in terms of heat, dust and fumes.
- As there is no combustible material in the FAR, the risk from fire in the intake is virtually nil.
- Any fire in the ramp will not affect workers in the ramp or on any level below that location in the ramp, which includes most of the high activity areas.
- Providing a basic pedestrian door is installed into the FAR system on each level, then any worker reaching the FAR on any level will be in a secure fresh air base and able to survive more or less indefinitely. Setting up a secure underground cribroom is easy with this system.
- Any ladderway in the FAR system will be in fresh air, providing a safe alternate means of egress, or a safe means for mine rescue teams to bypass a fire on the ramp for either search or rescue operations.
- If the mine does need cooling, then surface cooling is easy to introduce into the intake shaft. Compare this to a mine in which the intake is a surface portal with heavy traffic through it.

As mines get deeper, the combination of greater autocompression heat loads, higher VRTs with depth, greater t-km trucking loads and the lengthening intake ultimately dictate that some of external cooling will be required. The provision of 1 MW of cooling costs approximately A$0.5 to A$1.0 million (for surface cooling, double this for underground cooling) so that being able to remove three or four trucks from the intake can defer expenditure on cooling for perhaps a few years; alternately if cooling is required, taking the heat loads out of the intake can save substantial sums in capex and opex.

The style of primary ventilation outlined above achieves these objectives. If sufficient primary airflow is available, this system allows auxiliary fans to be set up on each level in a bulkhead at the FAR connection and to duct air directly to the workplaces, as shown in Figure 9. Air moves through a ventilation duct typically at about 20 m/s compared to perhaps 1 to 2 m/s in a normal airway. If the air is chilled, then getting it to the workplace as quickly as possible preserves its "coolth" and also keeps dust and gases out of the air delivered to the face.

Even if there is insufficient air for a single pass operation, operating the ramp as a return with fans below each level feeding the workplaces on each level (Figure 10) is still a preferable option to that shown in Figure 6.

Note that this style of ventilation requires the fan on the surface shaft to be a blowing fan. Contrary to popular thinking, the mine resistance is identical whether air blows through the mine one way or the other, and the fan curve is identical whether the fan operates in forcing or exhausting modes. Therefore the mine airflow will be identical with the fan reversed, and in many cases, the same fan can be used on the mine, with a redesigned elbow or connection at the shaft collar.

There are disadvantages of this system; however, most of these issues can be solved relatively easily.

- Trucks will be travelling upramp in the same direction as the exhaust on the ramp. To avoid trucks travelling in their own fumes, it is important that the wind speed on the ramp be higher than the truck upramp speed. Frequently, these trucks travel loaded upramp at about 10 kph or 2.8 m/s. With the ramp as the only exhaust, it would be unlikely that many sections of the ramp would have an airflow less than this value. Note that the air temperature of concern to a diesel engine is the dry bulb temperature of the surrounding air, not the wet bulb temperature and DB temperatures on the ramp with the mine ventilation reversed are not likely to be significantly above the values with the ramp as a dirty intake, and in some cases will be lower. Further note that the radiator on a truck relies on its fan to pull air over it. The truck speed is small and irrelevant compared to the induced wind speed from the fans. Some trucks even have the radiator facing sideways so it doesn't matter whether the truck is travelling with or against the wind.
- If the mine uses locally-initiated blasting, then blasting must start on the upper levels and progress downwards to ensure the person initiating the blasts is always in fresh air. Alternately, a mains or remote blasting system can be employed.
- Blasting fumes enter the main ramp and must travel to the surface. There is the potential for increased re-entry times; however, the blasting fumes are usually diluted with large volumes of air in the ramp from uncontaminated sources and re-entry times are usually not significantly affected.
- If areas such as fuel bays or magazines currently discharge into the RAR system, then these lose their exhaust and would need to discharge onto the ramp. However, in most cases, these areas are above the active working levels. In addition, it should be noted that an out-of-control fire in most refuelling stations or magazines in most mines would still enter the adjacent intake airway as the energy imparted into the air by the fire would swamp the small amount of exhaust provided to these facilities on most mine sites. In this case, using the ramp as the return is actually safer than current practices.
- Ventilation doors and flaps in the mine need to be rehung to open on the other side.
- Heat from blowing fan enters the top of the intake shaft. However, in a modern diesel-intensive mining operation, the heat load from a surface main fan is small compared to the diesel and auxiliary fans underground.
- The direction of leakage through old workings or any other place is reversed.
- Depending on the mine's location, nature of the operation and surface climate, some mines may experience fogging problems in the main ramp near the portal during certain periods of the year, although this issue is unlikely to be prevalent in most mines in Australia.

7. SUMMARY AND CONCLUSION

A current trend in mine ventilation uses the main ramp as the mine's sole intake ("dirty intake), with no exhaust on working levels ("series ventilation"). Contaminant levels due to diesel gases and heat are high in this design, the risk of recirculation due to short-circuiting increases, the potential for dead spots on the ramp is high, and the security of the system in the event of a fire is poor.

A further current trend towards placing the second means of egress (e.g. ladderway) in the exhaust system, or connecting it into the ramp system so that a fire on the ramp will pollute the second means of egress, is also bad practice.

The second means of egress should be a secure intake, isolated and independent of the primary means of egress. It should operate in a fail-safe manner even in the event of a complete underground power failure.

Ladderways are not suitable for escape by most modern underground workers. The second means of egress should principally be seen as the means for mine rescue to be able to bypass the primary means of egress for search and rescue operations, or to provide essential medical support for entrapped workers in refuge chambers.

A "rescue-ability" study should be undertaken for all mining areas; no fresh air base or refuge chamber in the mine should be beyond the ability of mine rescue.

The use of refuge chambers as a complete replacement for fresh air bases in underground mines should be prohibited. Refuge chambers should be seen as supplementary to fresh air bases, and basically as interim or local solutions rather than permanent solutions that negate the need for an effective ventilation system.

The most robust primary ventilation system for a mine with a surface ramp is to have at least one surface intake shaft and one surface exhaust shaft servicing all main working levels. The intake shaft can be equipped with a ladderway (or set up for emergency winding) and acts as both a secure second means of egress and also provides secure fresh air bases on each working level. The ramp operates as a neutral intake, i.e. downcasts only sufficient intake air from surface for its own purposes (i.e. to ventilate itself) and is not used to feed air into the working levels. This provides a highly secure and robust ventilation system. However, if under the ALARA principle, the operation cannot support such a design and only one surface shaft can be provided, then serious consideration should be given to using this surface shaft as the intake and using the ramp as the primary exhaust, under the influence of a surface blowing fan.

In all cases, the operation of the ventilation system must be carefully integrated with site operating practices and other controls, such as the selection and use of suitable self-contained self-rescuers, refuge chambers, fire detection systems and personnel notification systems.

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Table 3 Classification of intake and exhaust systems for major ventilation districts, individual levels and individual working places (RAR=return air raise, FAR = fresh air raise)

Intake to district or orebody
Secure isolated intake from surface pressurised by surface blowing fan
Secure isolated intake from surface drawn by surface exhausting fan
Semi- isolated intake from surface pressurised by surface blowing fan
Semi- isolated intake from surface drawn by surface exhausting fan
Secure isolated intake from surface drawn by underground blowing fans
Secure isolated intake from surface drawn by underground exhausting fans

Intake to each level
From district intake to each level via FAR on each level, EITHER • FARs under positive pressure, OR • FARs under negative pressure
From district intake into ramp system then into each level then into RAR on each level without returning to ramp
From district intake to ramp <u>bottom</u> (bypassing all levels) with each level fed re-used air from ramp acting as "dirty intake"
From district intake to ramp <u>top</u> (bypassing all levels) with each level fed re-used air from ramp acting as "dirty intake"

Intake to each job
Each face ducted direct from fans at FAR
Each face ducted from fans in fresh air, but not at FAR—<u>non-series</u> vent
Ducted from fans in fresh air, but not at FAR—<u>series</u> vent
Ducted from fans in ramp—<u>non- series</u> vent
Ducted from fans in ramp—<u>series</u> vent

Level Exhaust
To RAR on each level
To ramp

District/orebody exhaust
Directly into secure exhaust system to surface drawn by surface exhaust fans
Directly into secure exhaust system to surface drawn by underground circuit fans
Through other working areas to surface

Ramp ventilation	
Neutral intake (own supply of fresh air and ramp discharges into exhaust. Ramp air not used for other purposes)	- castin
	Up-casting
One-pass intake (ramp feeds each level with no air returning to ramp)	wn- cast .
	Up- cast ing
Dirty intake (ramp feeds each level in turn, with exhaust from level returning to ramp to feed next level)	wn- cast .
	Up- casti ng
Return (levels fed by own FAR system, but ramp collects all return air from levels)	Down- casting
	Up- casting