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OPPORTUNITY FOR RE-ENTRY INTO A COAL MINE IMMEDIATELY FOLLOWING AN EXPLOSION

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ABSTRACT: Following an explosion in a coal mine commentators within and outside the underground coal mining industry often make comment that the best time to enter the mine is immediately following the initial explosion. These comments often lead to the questioning of the action or lack of; if mines rescue services do not re-enter the mine.

The concept that there is a "window of opportunity" to enter a mine immediately following an explosion is based largely on the assumption that the fuel (mainly methane seam gas) required for an explosion has been consumed by the initial explosion and will take time to build up again to an explosive level.

This paper examines the merit of deploying personnel into an underground coal mine following an explosion.

INTRODUCTION

When persons remain unaccounted for underground following an explosion in a coal mine, there is a sense of urgency for rescuers to be deployed. Sending rescue teams underground must always take the safety of those deploying underground into consideration. McAteer, *et al.* (2011) made the following comment "In the United States alone, the history of mining and rescue efforts is filled with examples of rescuers being overcome by toxic gases or killed as a result of a second or third explosion"

A key consideration when sending in rescue teams is whether there is likely to be another explosion. For an explosion to occur an explosive gas mixture must come into contact with an ignition source. Prior to sophisticated mine gas monitoring systems being available to establish the status of the underground atmosphere, decisions were often based on the assumption that all of the methane was consumed in the initial explosion. If this was the case, a flammable gas mix would not be present, and a "window of opportunity" could exist until methane levels built up again, during which time mines rescue teams could enter the mine without risk of a second explosion. This assumption that no fuel existed justified deployment without the need to collect and evaluate data on the status of the underground environment. It was just assumed that this "window" existed.

The National Institute for Occupational Safety and Health's (NIOSH) Pittsburgh Research Laboratory undertook a project whereby they interviewed recognised experts in mine emergency response. Vaught *et al.* (2004) quoted one of the interviewees' on the perceived window of opportunity. "*We Bureau people [operated] on the theory that a majority of the methane in the place was burned out by the explosion, and I think that's another thing Scotia taught us-that doesn't necessarily happen. There's too many variables to even consider that I guess, but I think that was an assumption made by an awful lot of people. That depending upon the weight of liberation of that mine, you have a considerable amount of time to do some things before you had an explosive mixture reoccur. Well, that's not true.*"

The Australian coal mining industry has adopted a risk management approach to ensure that the risk that those in the industry are exposed to, is at an acceptable level. Mines rescue activities are not exempt from risk management processes in the conduct of their activities. Prior to deploying personnel underground following an explosion Australian mines rescue agencies will sample and evaluate the underground atmosphere and make decisions on re-entry based on the likelihood of secondary explosions. It is essential for the safety of the rescue teams that a conservative approach is taken towards the evaluation of secondary explosions. Evaluation of data may indicate that the risk to mines rescue teams if deployed underground would be unacceptable and as a result teams not be deployed. This understandably can be a source of frustration to all involved and where there is a time period

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between explosions, often leads to public questioning of the decision not to deploy rescue teams when a “window of opportunity” determined in hindsight existed.

The determination of whether a “window of opportunity” exists for re-entry into the mine can only be done with the data available to predict what could possibly occur.

REQUIREMENTS FOR AN EXPLOSION

For an explosion to occur a flammable gas mix must come into contact with an ignition source. Following an explosion there is every chance that an ignition source is present, either the ignition source of the initial explosion or a fire started by the explosion. A large volume of methane is not required for an explosion as it can simply be the catalyst for a coal dust explosion as is thought to be the case at Upper Big Branch Mine, 2010 (McAteer, *et al.*, 2011).

As already mentioned it is often assumed that an explosion will burn all of the available methane making entry to the mine safe immediately after an explosion. However this is not always the case and consideration must be given to the time it will take for rescue teams to enter the mine, carry out their tasks and exit the mine and the possibility of an explosion during this whole period.

Fuel sources

It is possible flammable mixes of methane can build up very quickly after an explosion. If the build up is in an area (not necessarily the same area as the initial explosion) where an ignition source exists a subsequent explosion can occur:

- The fuel for the initial explosion may have come from a non homogeneous mix of methane that contained fuel rich concentrations of methane that due to the “disturbance” of the explosion results in formation of an explosive atmosphere;
- The initial explosion damages seals segregating fuel rich atmospheres (high methane) that are released into the workings forming explosive gas mixes;
- Ventilation control devices such as stoppings and overcasts are destroyed or compromised by the initial explosion resulting in no ventilation in some areas and build up of methane;
- Methane drainage lines could be damaged allowing the flow of methane into workings;
- If the initial explosion was fuel rich then percentage levels of carbon monoxide and hydrogen may be generated. Both of these gases are flammable and under these circumstances can be generated in quantities great enough that a flammable gas mixture can exist even when methane is less than 5%;
- Combination of any or all of the above.

Example 1

If an initial explosion damages ventilation control devices compromising the ventilation to a 4 m x 5 m roadway 100 m long and damages a gas drainage pipe from which 60 l/s of methane flows, enough methane is generated for the whole roadway to be explosive in 29 minutes. Obviously with the methane coming from a point source a smaller explosive gas mix could be formed much faster and some means of mixing would be required for the whole roadway to be explosive.

Example 2

If rib emissions from a 5 m x 4 m roadway 2 km long total 125 l/s of methane then in 280 min enough methane is generated to make the whole roadway explosive if there is no ventilation.

Example 3

In a ventilation flow of 60 m³/s the required flow rate of methane to generate an explosive gas mix is 3.2 m³/s.

Volume of methane

The volume of methane estimated to have been involved in the 1979 Appin Colliery explosion that resulted in the deaths of 14 workers was much less than 400 m³ and probably less than 150 m³ based upon the maximum volume of the mine atmosphere that could have exploded.

The volume of methane involved in the initial 1994 Moura Number 2 explosion was estimated to be less than 70 m³, based upon the effects on the surviving miners (Stephan, *et al.*, 1994).

An explosion in 1995 at the Endeavour Colliery in New South Wales was determined to be as a result of approximately 6 m³ of methane being mixed with air to about 6-7% composition. This would indicate that the total volume of the flammable atmosphere that was ignited was only about 100 m³ (Anderson, *et al.*, 1997).

The amount of methane estimated as being involved in the initial explosion in 2000 at the Willow Creek Mine in Utah, United States of America was reported to be as little as 1.5m³ (McKinney, *et al.*, 2001).

In 2001 the initial explosion at the Jim Walter No. 5 Mine was determined to involve in the order of 3 m³ of methane (McKinney, *et al.*, 2002).

These examples show that the amount of methane required for an explosion with devastating consequences can be minimal and doesn't necessarily take long to accumulate.

REQUIREMENTS FOR RE-ENTRY

McAteer, *et al.*, (2011) identified the need for a scientific, numbers-based approach to mines rescue deployment stating in their report on the Upper Big Branch Explosion for the Governor "Life and death decisions - whether to send rescuers in or pull them back - are questioned, discussed and second-guessed, allowing the emotion of the moment to infringe upon the detached discipline and scientific approach that forms the basis of mine rescue. At its core, mine rescue is best served when decisions are based "on the numbers," the raw data as to the toxicity of the atmosphere and the potential for secondary explosions or fires. The emotion generated by media reports should not ever be a factor in those decisions. The mining community needs to address the rescue and recovery system in light of the new challenges presented by technology and the now ever-present media."

It is imperative therefore that if rescue operations are not going to expose rescue personnel to an unacceptable level of risk that the relevant information must be available or gathered and used in risk management processes for rescue operations. This means that prior to deploying mines rescue teams underground it is essential to ensure that an explosive gas mix cannot come into contact with an ignition source, including residual fires.

If a flammable gas mixture exists it must be positively established that an ignition source does not exist. Evaluation of the underground environment must be mine wide with consideration of interfaces between different sampling locations. Although accurate measurements of the flammable gases can be made, it must always be remembered that the samples being analysed at any location are just from that point and the concentration of gases around that sample location may not be the same. Put simply the sample point may not be representative of the whole area. A conservative approach is required in interpretation of the status underground and the requirement for a conservative approach is increased when insufficient sampling locations are available. It is more important to know at an early point in time when a location is trending towards an explosive gas concentration rather than when it has been reached.

EXAMPLES OF MULTIPLE EXPLOSIONS AT MINES

Raspadskaya mine

In May 2010 rescue teams were killed in a secondary explosion during underground rescue operations following an initial explosion three and a half hours earlier.

Jim Walter Resources No. 5 mine

In September 2001 two explosions occurred at the Jim Walter No. 5 Mine only 55 minutes apart resulting in the deaths of thirteen miners. At least twelve of the miners were killed in the second explosion. The amount of methane involved in the first explosion was determined to be in the order of 100 ft³. The second explosion also involved dust and a different ignition source.

Willow Creek

In 2000 there were four explosions at the Willow Creek Mine in Utah, United States of America. The timing between the first and second was seven minutes and then only one minute between the second and third with a fourth explosion twenty one minutes later. In total there were four explosions in twenty nine minutes. The amount of methane involved in the initial explosion was reported to be as little as 1.458 m³ (50 ft³). The initial explosion compromised ventilation assisting in the accumulation of methane and also started a fire (subsequent ignition source). The second explosion most likely created turbulence that caused high concentrations of methane in the goaf to mix with air.

Consol No.9 mine

In 1968 in Farmington, West Virginia the Consol No. 9 Mine suffered nine explosions over nine days with four in the first day alone. The second explosion was just two and a half hours after the first, with another two less than ten hours later. A day passed without further explosions but then two days after the initial explosion there were two within two hours. There was another nearly twelve hours later but then five days till the next, with the last explosion nearly one day after the previous.

A limited review on readily available information on incidents at mines involving more than one explosion is summarised in Table 1. There are multiple examples of second and third explosions within the first three hours, the time often referred to as being the "window of opportunity" for rescue operations. These examples show that there is no "window" during which it is safe to enter a mine after an explosion without risk of a secondary explosions and dispels the myth that all of the methane is used up in the initial explosion.

Table 1 - Examples of times between explosions

Period Between Explosions	Mine
0 - 5 mins	Castle Gate No. 2 Mine (usmra) Willow Creek (McKinney, <i>et al.</i> , 2001)
5 -10 mins	Willow Creek (McKinney, <i>et al.</i> , 2001)
10 - 20 mins	Castle Gate No. 2 Mine (usmra) Robena No. 3 (usmra) Eccles Nos 5 and 6
20 - 30 mins	Willow Creek (McKinney, <i>et al.</i> , 2001)
30 - 60 mins	Jim Walter Resources No. 5 Mine (McKinney, <i>et al.</i> , 2002)
1 - 3 hrs	Consol No.9 Mine (usmra) Consol No.9 Mine (usmra) Sayreton No. 2 Mine (usmra)
3 - 6 hrs	Bilsthorpe Colliery (usmra) Raspadskaya Mine (Marquardt 2010) Consol No.9 Mine (usmra)
6 - 12 hrs	Pond Creek No. 1 Mine(usmra) Consol No.9 Mine (usmra)
12 - 24 hrs	Consol No.9 Mine(usmra) Consol No.9 Mine (usmra)
1 - 2 days	Consol No.9 Mine (usmra)
2 - 3 days	Scotia Mine (usmra) Moura No. 2# Pike River Mine# Pike River Mine#
3+ days	Consol No.9 Mine (usmra) Pike River Mine#

- Author's own notes

CONCLUSIONS

- It is possible for flammable mixtures to build up very quickly after an explosion;
- Relatively small volumes of methane in explosive mixtures can have significant consequences if ignited;
- There are no fixed rules or guidelines for timing between explosions that can be followed after an initial explosion that allows a guaranteed non explosion period and every case needs to be assessed;
- Deployment of mines rescue personnel needs to be risk managed;
- Decisions on whether to send rescue teams underground or to withdraw them once deployed need to be done so based on a scientific approach using data on the explosibility of the underground workings.

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