From Scotia to Brookwood, fatal US underground coal mine explosions ignited in intake air courses

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A B S T R A C T

The National Institute for Occupational Safety and Health, Pittsburgh Research Laboratory, conducted a study of past mine explosions to identify the ignition locations and ignition sources responsible for the most severe explosion events resulting in death. Since the Scotia disaster of 1976, many fatalities from underground coal mine explosions have been linked to nonpermissible electrical equipment ignition sources located in intake air courses. With few exceptions, explosion protected equipment is generally not required in intake air courses of gassy underground coal mines in the US. Cigarette lighters were another prevalent ignition source for fatal explosions ignited in intake air courses. Several mine rescue/recovery teams have encountered electrical ignition hazards. The study provides evidence that intake air courses of gassy underground coal mines fit the description of certain Hazardous (classified) locations described in the US National Electrical Code®. Class I Division 2 or Zone 2 explosion protection techniques may be used to design intake air equipment so that it does not present an ignition source under normal operation, before mine power is shut down in emergency situations. Nonpermissible circuits in intake air courses that are likely to remain energized during emergencies, e.g. battery powered equipment, should be protected by more stringent Class I Division 1, Zone 1, or Zone 0 techniques, to protect rescue/recovery personnel.

1. Introduction

Several prominent US underground coal mine explosion disasters have been linked to electrical ignition sources located in intake air courses. Thirteen miners were killed during the 2001 Jim Walter Resources No. 5 mine, Brookwood, AL, double explosion disaster (MSHA, 2002; UMWA, 2003). The Mine Safety and Health Administration (MSHA) investigation concluded that both Brookwood explosions were probably ignited in intake air entries, and both were probably ignited by electrical equipment. Twenty-six miners were killed during the 1976 Scotia KY double explosion disaster (Bethell, 1976; Richmond, Price, Sapko, & Kawenski, 1983; USMRA, 2007). The US Mine Rescue Association (USMRA) attributes the ignition source for the first explosion (15 killed), to a normally sparking battery powered locomotive in an intake air entry. The large loss of life from the Scotia and Brookwood disasters suggested that, even though releases of flammable gas into intake air courses may be infrequent, ignition of these releases by nonpermissible electrical equipment can lead to large numbers of fatalities.

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Title 30 of the US Code of Federal Regulations (CFR) contains federal coal mining safety regulations (30 CFR). The term permissible refers to equipment that meets MSHA specifications for the construction and maintenance of such equipment, to assure that such equipment will not cause a mine explosion or mine fire (30 CFR 75.2). Electrical equipment that is normally exposed to methane or coal dust inby (closer to the working face than) the last open crosscut (30 CFR 75.500), or within 150 feet of pillar workings or longwall faces (30 CFR 75.1002), or in return entries (30 CFR 75.507), must be permissible. Any atmospheric monitoring system operated during fan stoppages shall be intrinsically safe (30 CFR 75.313). Air quality detectors and measurement devices shall be approved and maintained in permissible and proper operating condition (30 CFR 75.320). Telephones and signaling devices shall offer no probable explosion hazard under normal operation if used in gassy or dusty mine atmospheres (30 CFR 23.6). Electrical components of automatic fire sensors must be provided with protection against ignition of methane or coal dust (30 CFR 75.1103-7). With these few exceptions, explosion protected electrical equipment is generally not required in intake air courses of gassy underground coal mines in the US.

The National Institute for Occupational Safety and Health, Pittsburgh Research Laboratory, conducted a study of past mine explosions to identify the ignition locations and ignition sources responsible for the most severe explosion events resulting in death. (The findings and conclusions in this report are those of the author and do not necessarily represent the views of the National Institute for Occupational Safety and Health.) Fatalities linked to nonpermissible equipment ignition sources in intake air courses were compiled and compared to other ignition sources and ignition locations, to put the hazard posed by nonpermissible equipment in intake air courses into perspective. Recommendations are provided for preventing similar disasters in the future.

2. Historical summaries of coal mine explosions

US Bureau of Mines historical summaries of coal mine explosions provide many examples of explosions that were ignited by electrical equipment such as trolley wires and motor control contactors (Dobroski, Stephan, & Conti, 1996; Humphrey, 1960; Richmond et al., 1983). These summaries used the term *disaster* to describe events producing at least 5 fatalities. In the most recent summary, Dobroski et al. (1996) provided overviews and causal analyses of coal mine explosions from 1981 to 1994. Causal analyses involved only violations of MSHA regulations, which did not include normally sparking equipment in intake air entries. For example, the McClure mine explosion in 1983 (7 killed), was ignited by electrical arcing in possibly 6 pieces of equipment in intake air courses, but the causal analysis involved only ventilation practices. The causal analysis was similar to the Brookwood investigation in this respect, which also made no mention of the electrical equipment design in the causal analysis (MSHA, 2002). Some explosions in Dobroski et al.'s (1996) summary tables were categorized as electrical, but a distinction was not made as far as the location of the equipment, or if the equipment was faulted permissible equipment or normally sparking electrical equipment. In the current study, fatalities linked to nonpermissible equipment ignition sources in intake air courses were compiled and compared to other ignition sources and ignition locations, to put the hazard posed by nonpermissible equipment in intake air courses into perspective.

Dobroski et al.'s (1996) summary tables did not account for uncertainties associated with multiple possible ignition sources or ignition locations. For example, the summary tables attributed the Pyro William Station Mine disaster of 1989 to a cutting torch even though the gas valves on the torch were found closed. The narrative description of the explosion pointed out that other types of ignition sources were considered possible in no particular order of likelihood. The possible ignition sources were at the face or in an intake air course. In the current study, explosion fatality summaries were weighted for cases where a most likely ignition source or location was not identified, to better account for multiple potential ignition sources and locations for comparison purposes.

3. Surveillance study methods

Fatal accidents categorized as *ignition* or *explosion* since 1976 were identified through the Mining Accident, Injury and Illness (MAII) database (NIOSH, 2007). MSHA investigation reports for fatal accidents since 1995 were downloaded from the MSHA web site (MSHA, 2007). Fatal accident reports prior to 1995 were obtained from the MSHA Technical Information Center and Library, Beckley WV. Richmond et al.'s (1983) and USMRA (2007) accounts of the Scotia disaster were used because an MSHA investigation report was never released. The review did not include MSHA fatal reports categorized as *fire*. The review did not include fatal reports categorized as *explosives* that did not also involve ignition of gas or dust. High wall mines, which are categorized as surface mines, were included in the study because they involved explosions of methane and coal dust ignited in openings mined under the surface.

Ignition locations were categorized as follows.

- *Unsealed Gob* refers to the space left by the extraction of a coal seam into which waste is packed or the immediate roof caves and the area had not yet been sealed from the active workings.
- *Sealed area* refers to a worked-out area (30 CFR 75.301) that is sealed. Sealed areas were not required to be maintained as an inert atmosphere prior to 2007.
- *Return* air is defined as air that has ventilated the last working place on any split of any working section or any worked-out area, whether pillared or nonpillared (30 CFR 75.301).
- *Intake* air is defined as air that has not yet ventilated the last working place on any split of any working section, or any worked-out area, whether pillared or nonpillared (30 CFR 75.301.) Intake air is taken to include belt air course, as 30 CFR does not make a distinction between intake and belt air course for electrical equipment permissibility purposes in methane contaminated atmospheres.
- *Shaft* refers to a vertical or near vertical excavation in rock for the purpose of providing access to an ore body.
- A *high wall opening* refers to an underground excavation into the wall of an open-cut excavation.
- A working face is defined as any place in a coal mine in which work of extracting coal from its natural deposit in the earth is performed during the mining cycle (30 CFR 75.2). *Face* refers to areas inby the last open crosscut up to the working face or within 150 feet of pillar workings or longwall faces.

Electrical equipment ignition sources were subdivided into two categories.

- *Faulted permissible equipment* refers to permissible equipment that malfunctioned in a manner that defeated the explosion protection feature of the equipment.
- *Nonpermissible equipment* refers to electrical equipment not identified as permissible and not required to be explosion protected. *Vehicle* refers to locomotives or personnel carriers. *Vehicle* ignition source categories were subdivided as battery powered and trolley wire powered.

For cases where a single most likely ignition source or location was not identified, the number of fatalities attributed to categories of ignition sources or locations were weighted by the uncertainty associated with each. For example, if an explosion resulted in 10 fatalities, and two possible ignition locations with five possible ignition sources were identified in no particular order of likelihood, each ignition location was attributed 5 fatalities, and each ignition source was attributed 2 fatalities.

4. Results

Appendix Table A1 lists fatal methane and/or coal dust explosions in underground and high wall coal mines since 1976. All intake air entry explosions occurred when the ventilation system failed or was determined to be inadequate. All fatal intake air entry explosions involved only methane initially. The severities of some of these explosions were enhanced by coal dust suspensions *after* the methane was ignited.

The 1989 Pyro No. 9 explosion disaster originated in one of two different locations and could have been ignited by 5 different types of ignition sources. An intake air entry was identified as the transition zone where a strong explosion developed, but a weaker explosion originating on a longwall face that propagated to the transition zone was also plausible. A cutting torch and igniter were found at the face, although both gas valves on the torch were found closed. A permissible scoop with multiple faults was found at the face. An undetonated blasting cap was found near the transition zone, suggesting blasting caps conceivably could have been involved. A roof fall with pyritic inclusions occurring in the transition zone was a conceivable ignition source. A messenger wire strung through the transition zone that could have snapped under tension was a conceivable ignition source. The most likely ignition location or source could not be determined.

The 1983 McClure and 1987 Double R explosions involved multiple possible electrical ignition sources in no particular order of likelihood. All six electrical ignition sources identified for the seven McClure explosion fatalities involved equipment not identified as permissible. Three of the four possible electrical ignition sources identified for the Double R explosion fatality involved equipment not identified as permissible.

One of the Brookwood miners may have received fatal injuries from the first explosion prior to the second massive explosion. This fatality was attributed to the first 2001 Brookwood explosion in Table A1. The battery assembly cited as the ignition source of the first explosion had been removed from a permissible scoop and was located at a nonpermissible charging station.

The fatality for the 1987 Dutch Creek No. 2 ignition suffered a myocardial infarction while fighting a fire resulting from the ignition. The miner later died from a cardiac arrhythmia. A fatality review committee decided the accident was chargeable to the mining industry because the conditions surrounding the miner's fire fighting activities contributed to his death. The MSHA investigation report classified this accident as a fatal methane–air ignition.

Using Table A1 data, Figs. 1–5 show fatalities linked to different locations and ignition sources. In Fig. 1, the numbers of fatalities per location were weighted by the uncertainty of the location of the 1989 Pyro No. 9 disaster. Of the ten 1989 Pyro fatalities, 5 were attributed to a face ignition and 5 were attributed to an intake air entry ignition. 71 of 160 fatalities were linked to intake air courses using this weighting method (Fig. 1). Considering all fatalities from the 1989 Pyro disaster, 76 fatalities were linked to intake air courses. In Fig. 2, numbers of fatalities per category were weighted by ignition source uncertainties of the 1989 Pyro No. 9 disaster and 1987 Double R explosion. In Fig. 3, numbers of fatalities per category were weighted by ignition source uncertainties of the 1989 Pyro No. 9 disaster and 1987 Double R explosion. In Fig. 4, numbers of fatalities per category were weighted by ignition source uncertainties of the 1983 McClure disaster and the 1987 Double R explosion.

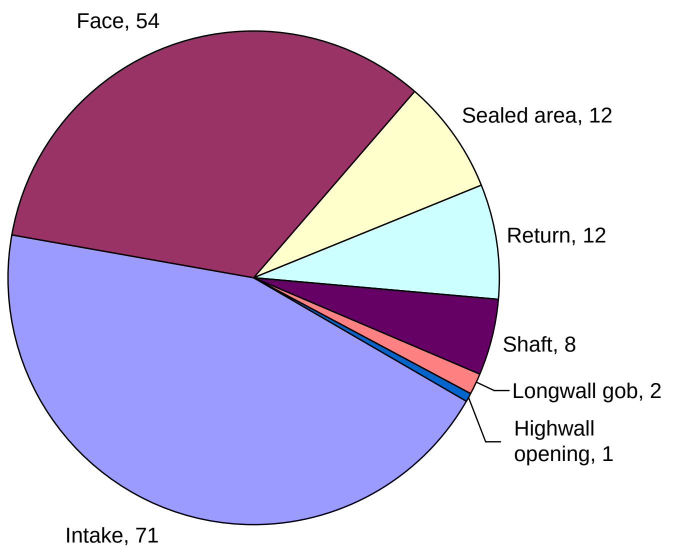

Fig. 1. 160 methane and/or coal dust explosion fatalities by location of the ignition source in underground or high wall coal mines from 1976 to 2006. Numbers of fatalities per location were weighted by the location uncertainty of the 1989 Pyro No. 9 disaster.

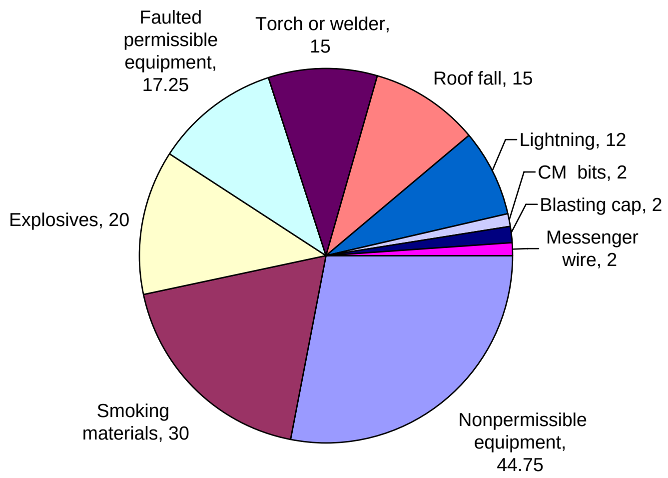

Fig. 2. Ignition sources linked to 160 methane and/or coal dust explosion fatalities in underground and high wall coal mines from 1976 to 2006. Numbers of fatalities per category were weighted by ignition source uncertainties of the 1989 Pyro No. 9 disaster and 1987 Double R explosion.

5. Discussion

5.1. Class I hazardous locations

Certain techniques are used to design electrical equipment to protect against igniting explosions in locations where flammable materials may be encountered under normal or abnormal conditions. These locations are classified as Hazardous locations described in the National Electrical Code® (NEC®)[1]. NEC® Article 500 describes Division locations, while AT:/PGN/ELSEVIER/JLPP/22(1)/web/00002010/rticle 505 describes Zone locations (NEC, 2005). The requirements for Divisions and Zones differ somewhat because the Division system was developed in the US while the Zone system was developed in Europe. Zones were recognized in the NEC® beginning in 1996. NFPA 497 and NFPA 499 provide guidelines for classifying Hazardous Locations.

One description of Class I Division 2 or Zone 2 is a location where ignitable concentrations of gases or vapors are normally prevented by positive mechanical ventilation, and which might become hazardous through failure or abnormal operation of the ventilating equipment (NEC 500.5(B)(2); 505.5(B)(3)). Division 2 and Zone 2 were established to allow the use of less expensive equipment and less restrictive wiring methods as a more practical approach to preventing explosions in locations that become flammable only under infrequent, abnormal situations (Babiarz, 2004). Babiarz, Delans, and Hughes (1997) conducted a survey that found Division 2 classified locations were by far the most common Hazardous (classified) locations in North American industries at risk from ignition of flammable materials, outside of the underground coal mining industry. A rule of thumb for Division 2 or Zone 2 equipment is that it should not be an ignition source under normal operation. Redundant safety features are generally not required. The safety justification for the equipment is that the explosion protection features are not likely to fail simultaneously with the

[1] *National Electrical Code®* and *NEC®* are registered trademarks of the National Fire Protection Association, Quincy MA.

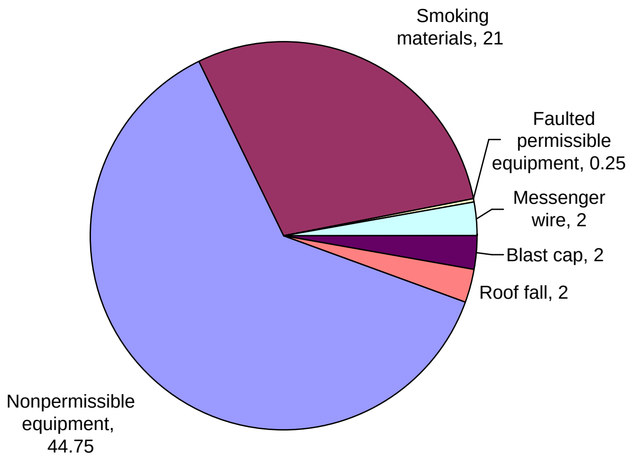

Fig. 3. Methane and methane plus coal dust explosion fatalities linked to ignition sources in intake air courses of underground coal mines from 1976 to 2006. Numbers of fatalities per category were weighted by ignition source uncertainties of the 1989 Pyro No. 9 disaster and the 1987 Double R explosion.

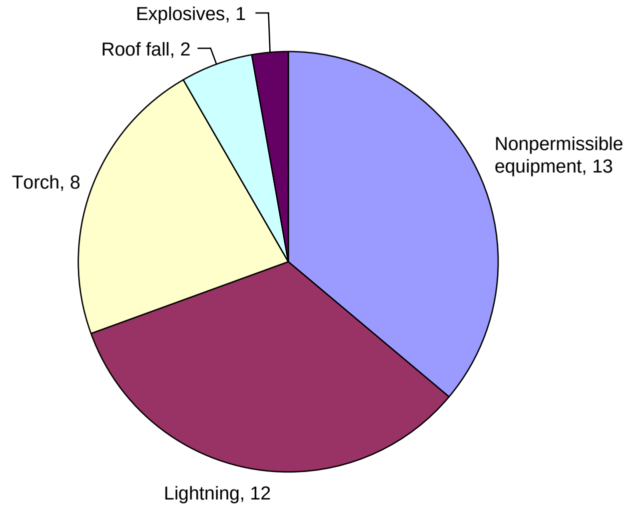

Fig. 5. Most likely ignition sources identified by MSHA for 36 fatalities from methane and methane plus coal dust explosions in underground coal mines from 2000 to 2006.

infrequent process failure that releases the flammable material. The less redundant or robust features of Division 2 or Zone 2 equipment reflect the layer of protection already provided by the flammable material containment or ventilation system to prevent the flammable atmosphere from contacting the electrical equipment. Requirements for Division 2 or Zone 2 approved equipment imply that when lives are at stake, a good ventilation system should not be used in place of the protected equipment; rather, the protected equipment is a *necessary* layer of protection along with the ventilation system.

One condition for Class I Zone 2 locations is that if a flammable atmosphere is released, it will exist only for a short period (NEC 505.5(B)(3)). During mine emergencies, however, battery powered equipment may be abandoned and exposed to methane for an extended period of time. More stringent Class I Division 1, Zone 1 or Zone 0 protection would therefore be necessary for battery powered equipment abandoned during a mine emergency. One description of a Class I Division 1 or Zone 1 location is a location in which ignitable concentrations of flammable gases or vapors can or are likely to exist under normal operating conditions (NEC 500.5(B)(1); 505.5(B)(2)). Class I Division 1 overlaps with Zone 0, which is a location where flammable gases or vapors are present continuously or for a long periods of time (NEC 505(B)(1)).

The Hazardous Class refers to the flammable material; Class I materials are flammable gases and vapors (NEC 500.5 (B)). Methane is a Class I Group D (Division system) or Class I Group IIA (Zone system) flammable material. Class I Group I (Zone system) refers to firedamp, defined as a mixture of gases, composed mostly of methane, found underground, usually in mines. NFPA 497 provides guidelines for classifying flammable liquids, gases, or vapors.

5.2. Risk assessment for explosion protected equipment

A risk assessment approach for the acceptance of explosion protected equipment has been introduced by the International Electrotechnical Commission, Technical Committee 31 (IEC TC 31), as an alternative method to the current prescriptive practice linking equipment to Zones (IEC 60079-0). To facilitate this, a system of equipment protection levels (EPLs) has been introduced to indicate the inherent ignition risk of the equipment, no matter what type of protection is used. For coal mining, EPL Ma refers to equipment having a "very high" level of protection, which has sufficient security that it is unlikely to become an ignition source, even when left energized in the presence of an outbreak of gas. Typically, communication circuits and gas detection equipment would be constructed to meet the Ma requirements. EPL Mb refers to equipment having a "high" level of protection, which has sufficient security that it is unlikely to become an ignition source in the time span between there being an outbreak of gas and the equipment being de-energized. Typically all coal mining equipment would be constructed to meet the Mb requirements, for example flameproof motors and switchgear. EN 1127-2 describes basic explosion prevention concepts for mining equipment used in Europe. EN 1710 notes that high energy mining equipment batteries cannot be de-energized when an explosive atmosphere occurs, and are ignition-protected according to EN 60079-7 as type "e" – 'increased safety apparatus'. Groh (2004) explains "increased safety" among other

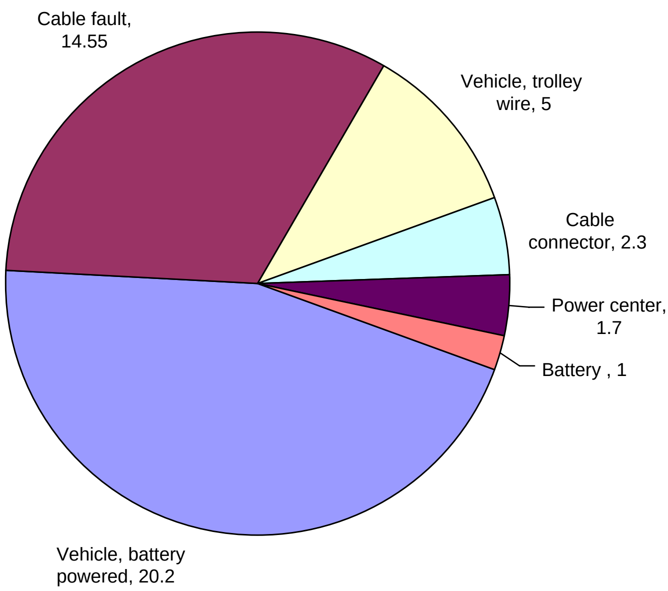

Fig. 4. Methane and methane plus coal dust explosion fatalities linked to non-permissible electrical equipment in intake air courses from 1976 to 2006. Numbers of fatalities per category were weighted by ignition source uncertainties of the 1983 McClure disaster and the 1987 Double R explosion.

explosion protection techniques for underground coal mining equipment commonly used outside of the US.

5.3. Intake air course hazards

Fig. 1 shows that many US explosion fatalities since 1976 can be linked to ignition sources in intake air courses. In all of these accidents, the ventilation system failed or was found to be inadequate. These fatalities suggest intake air courses of gassy underground coal mines should be considered Class I Division 2 or Zone 2 locations at a minimum, i.e. locations in which flammable gases or vapors are normally prevented by positive mechanical ventilation, and which might become hazardous through failure or abnormal operation of the ventilating equipment (NEC 500.5 (b) (2); 505.5 (b) (3)).

All intake air ignitions involved methane initially. The severity of some of these explosions was enhanced by coal dust suspensions *after* the methane was ignited. Equipment designed for methane atmospheres would reduce the risk of fatal explosions compared to the risk of using normally sparking equipment in intake air courses of gassy underground coal mines. This does not preclude the need to protect against hazards from coal dust layers that may accumulate on equipment or in entries, posing a fire hazard or explosion enhancement hazard after the dust is entrained in the air. 30 CFR 75 subpart E addresses combustible materials and rock dusting. 30 CFR 75 subpart L addresses fire hazards. Direct ignition of coal dust suspensions is a primary concern when using explosives. 30 CFR 75 subpart N addresses explosives and blasting.

Figs. 2 and 3 show that nonpermissible equipment can be linked to more explosion fatalities than any other ignition source category, for all locations, and especially in intake air courses. Fig. 5 shows this trend continues to recent times. All of the nonpermissible equipment ignition sources linked to explosion fatalities were located in intakes. Fig. 4 shows that nonpermissible vehicles (battery and trolley powered) were linked to most intake explosion fatalities. Today, several underground vehicle manufacturers offer explosion protected locomotives and personnel carriers, track or tire, battery or diesel. Given the history of vehicle ignited fatal explosions and the availability of explosion protected vehicles, use of explosion protected vehicles in intake air courses of gassy underground coal mines is recommended to reduce this hazard.

Twelve of the cable fault fatalities (Fig. 4) can be linked to the damaged block light cable igniting the second massive Brookwood explosion. The block light system was not required to be designed to prevent methane ignition as it was installed in an intake air entry. The description of the block light circuit (MSHA, 2002) suggests the block light installation may not have met several requirements for flexible cords in Class I Hazardous Locations (2005 NEC 501.140; 505.17)[2]. Potential violations involved: lack of a separate grounding conductor, cord not listed for extra hard usage, cord not protected from damage by location or suitable guard. Compliance with these NEC® and OSHA requirements might have prevented the 2nd 2001 Brookwood explosion (Dubaniewicz, 2007).

30 CFR 75.323 directs workers to disconnect electrical circuits at the power source when excess methane is present. Disconnecting circuits can produce an incendiary spark. Yet, explosion protected disconnects are not required in intake air entries that may become flammable during emergencies, when the ventilation system fails. Activation of nonpermissible circuit breakers in power centers were implicated in the 1987 Double R and 1983 McClure fatal explosions. The most likely ignition source for the first 1976 Scotia explosion was arcing created by the open type electric motor controller on the locomotive when the controller was turned to the "off" position. Thirty years later, a miner disconnected battery leads to a nonpermissible vehicle during the early stages of the 2006 Sago disaster. This action was prompted by a carbon monoxide alarm alerting the miner to bad air. Even if a methane monitor alarm had sounded in this situation, a literal interpretation of 30 CFR 75.323 would have directed this miner to disconnect the circuit in the presence of excess methane. Shutting off a light switch in a faulted explosion proof enclosure while evacuating during a methane outburst was the likely ignition source for the 1981 Dutch Creek disaster, 15 killed. Although the enclosure was faulted, this disaster is a horrific example of the dangers of disconnecting unprotected circuits in a flammable atmosphere. Inspection, maintenance, and repair of explosion protected equipment are of paramount importance. Explosion protection is recommended for all electrical disconnects in intake air courses that may activate automatically or be activated manually in the presence of excess methane during emergencies.

Most fatalities linked to cigarette lighters occurred when the miner was lighting up in intake air courses (Fig. 3). Smoking materials are prohibited in underground coal mines (30 CFR 75.1702). The smoking related fatal explosions emphasize the hazard of open ignition sources located in intake air courses of gassy mines should the ventilation system fail or become inadequate. The use of explosion protected electrical equipment in intakes of gassy mines may make the miner more aware of ignition hazards in these areas, including smoking materials.

5.4. Rescue team hazards

Rescue/recovery teams have encountered electrical ignition sources, some with fatal consequences. An energized block light circuit was the likely ignition source for the second 2001 Brookwood explosion, killing all of the rescuers. While recovering the deceased miner from the 1987 Double R explosion, the recovery team encountered an arcing cable connected to a battery. Following the 2001 Brookwood disaster, the United Mine Workers of America recommended rubber conduit be placed over battery charging cables. This recommendation would have also applied 15 years earlier to the 1987 Double R explosion. 1989 Pyro recovery personnel encountered a faulted permissible battery powered scoop tractor with a pump motor running. 2006 Sago rescuers encountered a battery powered mantrip with lights on. Class I Division 2 or Zone 2 techniques are not appropriate for circuits that may be immersed in a flammable atmosphere for a long time during a mine emergency. More stringent Class I Division 1, Zone 1, or Zone 0 techniques are recommended for nonpermissible battery powered equipment in intake air courses, to protect rescue and recovery personnel.

6. Recommendations

Since 1976, many fatalities from explosions in gassy underground coal mines can be linked to ignitions in intake air entries, when the ventilation system failed or was inadequate. The fatal explosions ignited in intake air courses of gassy underground coal mines involved only methane initially. The severity of some of these explosions was enhanced by coal dust suspensions only after the methane was ignited. The fatality data suggests intake air entries that may become flammable should the ventilation system fail should be considered Hazardous (classified) Locations per the NEC®, Class I Division 2 or Zone 2 at a minimum.

[2] The 1999 NEC® was in effect at the time of the Brookwood disaster. Requirements for flexible cords in Class I hazardous locations are found under Article 501-11 of the 1999 NEC®.

Many fatalities from explosions ignited in intake air entries can be linked to electrical equipment. Class I Division 2 or Zone 2 explosion protection techniques are recommended for non-permissible equipment used in intake air courses so that it does not present an ignition source under normal operation, before the power source is removed in the event of an emergency. Non-permissible equipment that is likely to remain energized during emergencies, e.g. battery powered equipment, should be protected by more stringent Class I Division 1, Zone 1, or Zone 0 techniques, to protect rescue/recovery personnel. US mining industry participation with the IEC to develop a risk assessment approach for the acceptance of explosion protected mining equipment is recommended.

Of the nonpermissible equipment ignition sources, vehicles were linked to most intake explosion fatalities. Use of explosion protected vehicles in intake air courses of gassy underground coal mines is recommended to reduce this hazard. Compliance with NEC requirements for flexible cords in Class I Hazardous Locations is recommended to reduce the ignition hazard of cable faults in intake air courses of gassy underground coal mines. Explosion protection is recommended for all electrical disconnects in intake air courses of gassy mines that may activate automatically or be activated manually in the presence of methane during emergencies. Inspection, maintenance, and repair of explosion protected equipment are of paramount importance.

The smoking related fatalities emphasize the hazard of open ignition sources located in intake air courses or other active workings of gassy mines where miners are normally required to work or travel.

Acknowledgements

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Appendix

Table A1
Fatal methane and/or coal dust explosions in underground and high wall coal mines 1976–2006

Year	Operator, mine, and state	Fuel	Ignition location	Ignition sources	Killed
1976	Scotia Coal Co., Scotia Mine, KY	Methane	Intake	Normal arcing of battery powered locomotive	15
1976	Scotia Coal Co., Scotia Mine, KY	Methane & coal dust	Face	Roof fall onto roof bolter	11
1977	P & P Coal Co., #2 mine, VA	Methane	Return	Cigarette lighter	4
1977	Bethlehem Mines Corp., Revloc #32, PA	Methane	Shaft	Torch	1
1980	Westmoreland Coal Co., Ferrell #17 Mine, WV	Methane	Intake	Trolley wire powered locomotive	5
1981	Mid-Continent Resources, Inc., Dutch Creek #1 Mine, CO	Methane & coal dust	Face	Faulted explosion proof enclosure on continuous miner (CM)	15
1981	Adkins Coal Co., #11 Mine, KY	Coal dust	Face	Detonation of explosives	8
1981	Grundy Mining Co., #21 Mine, TN	Methane	Intake	Cigarette lighter	13
1982	RFH Coal Co., #1 Mine, KY	Coal dust	Face	Detonation of explosives	7
1983	Clinchfield Coal Co., McClure #1 Mine, VA	Methane	Intake	Battery powered track mounted mantrip, power center circuit breaker, dinner hole light connection, cable plug for CM trailing cable, belt control cable disconnect or fault, ground fault in trailing cable for conveyor belt feeder.	7
1983	Helen Mining Co., Homer City Mine, PA	Methane	Intake	Arcing controller on vehicle	1
1984	Pennsylvania Mines Corp., Greenwich Collieries #1 Mine, PA	Methane	Intake	Normal arcing of nonpermissible battery powered locomotive	3
1985	M.S.W. Coal Co., #2 Slope, PA	Methane	Face	Detonation of explosives	3
1986	Pyro Mining Co., Pyro #9 Slope, William Station Mine, KY	Methane and/or coal dust	Face	Detonation of explosives	1
1987	Mid-Continent Resources Inc., Dutch Creek #2 Mine, CO	Methane	Face	CM bits struck sandstone roof	1
1987	Double R Coal Co., #1 Mine, VA	Methane & coal dust	Intake	Two power centers, battery charging cable, faulted permissible scoop.	1
1989	Pyro Mining Co., Pyro #9 Slope, William Station Mine, KY	Methane	Face or intake	Faulted permissible scoop at face, torch or igniter at face, blasting cap in intake, roof fall in intake, messenger wire tensile failure in intake	10
1991	Fire Creek Inc., #1 Mine, WV	Methane	Face	Cigarette lighter or match	2
1991	Addwest Mining Inc., Watson Bridge Mine, KY	Methane & coal dust	Highwall opening	CM bits struck hard roof	1
1992	Consolidation Coal Co., Blacksville #1 Mine, WV	Methane	Shaft	Welding sparks	4
1992	Southmountain Coal Co., #3 Mine, VA	Methane & coal dust	Intake	Cigarette lighter	8
1993	A.A.&W. Coal Co., Elmo #5 Mine, KY	Methane & coal dust	Return	Cigarette lighter	1
1994	Day Branch Coal Co., #9 Mine, KY	Methane & coal dust	Return	Cigarette lighter	2
2000	Plateau Mining Corp., Willow Creek Mine, UT	Methane	Unsealed gob	Roof collapse ignited 1st explosion, subsequent oil and coal fire ignitedmore explosions	2

(*continued on next page*)

Table A1 (*continued*)

Year	Operator, mine, and state	Fuel	Ignition location	Ignition sources	Killed
2001	Jim Walter Resources Inc., #5 Mine, Brookwood AL	Methane	Intake	Battery assembly removed from scoop and damaged by roof fall	1
2001	Jim Walter Resources Inc., #5 Mine, Brookwood AL	Methane & coal dust	Intake	Damaged block light cable	12
2003	McElroy Coal Co., McElroy Mine, WV	Methane	Shaft	Cutting torch	3
2006	International Coal Group, Sago Mine, WV	Methane	Sealed area	Lightning	12
2006	Kentucky Darby LLC, Darby Mine #1, KY	Methane & coal dust	Return	Torch	5
2006	R&D Coal Co., PA	Methane	Face	Explosives	1
Total					160

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