The Brookwood Disaster and Electrical Requirements for Hazardous (Classified) Locations

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Abstract - **Thirteen miners died as a result of 2 explosions in the Jim Walter Resources No. 5 mine near Brookwood AL in September 2001. Both explosions were ignited in intake air entries, and both were probably ignited by electrical equipment. With few exceptions, permissible equipment is not required in intake air entries of US underground coal mines. Researchers with the National Institute for Occupational Safety and Health, Pittsburgh Research Laboratory, studied the electrical equipment ignition sources for the Brookwood and other disasters to develop recommendations for preventing similar disasters. Adherence to National Electrical Code® requirements for flexible cords installed in hazardous (classified) locations may have prevented the second massive Brookwood explosion. The 30 CFR Part 7 requirements for battery assemblies should be reevaluated, taking into consideration United Mine Workers of America recommendations and the Zone 1 "increased safety" standard requirements for battery assemblies. Class I Division 2 or Zone 2 explosion protection techniques are recommended for intake air equipment so that they do not present a methane-air ignition source under normal operation, before mine power is shut down during emergencies. Battery powered circuits in intake air that are likely to remain energized during emergencies should be protected by more stringent protection techniques, to protect rescue/recovery personnel.**

Index Terms – **Class I hazardous location, mine explosion, flexible cord, battery assembly, permissible equipment**

I. INTRODUCTION

Gas or dust explosions are some of the greatest hazards faced by underground coal mine workers. Explosions may be infrequent, but can account for large numbers of deaths when they do occur. Methane gas is released during the mining process and accumulates in areas that are not well ventilated. Coal dust accumulations can form explosive dust clouds when entrained into the air. Methane ignitions or explosives can disperse coal dust layers into the atmosphere that subsequently ignite and propagate as powerful explosions. Over the last 30 years, a number of fatal underground coal mine explosions have been linked to nonpermissible electrical equipment ignition sources when flammable gas migrated outby the last open crosscut under abnormal conditions due to inadequate ventilation (Table 1) [1]. The most recent of these fatal intake air explosions occurred at the Jim Walter Resources (JWR) Inc. No. 5 mine near Brookwood AL in September of 2001, where 13 miners died as a result of 2 explosions involving methane and coal dust, both of which were ignited in intake air entries, and both of which were probably ignited by electrical equipment. Researchers with the National Institute for Occupational Safety and Health, Pittsburgh Research Laboratory (NIOSH, PRL) studied the electrical equipment ignition sources for the Brookwood disaster to develop equipment design recommendations for preventing similar disasters in the future (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.) The equipment studied was described in the Mine Safety and Health Administration [2] and United Mine Workers of America [3] reports on the disaster.

The term permissible refers to equipment that meets 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) [4]. Electrical equipment that is normally exposed to methane or coal dust inby 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. 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). The explosion protection techniques most familiar to the underground coal mining industry are explosion proof enclosures and two-fault intrinsic safety. With few exceptions, explosion protected electrical equipment is generally not required in intake air entries of underground mines.

II. THE 2001 BROOKWOOD DISASTER

On September 23, 2001, two explosions occurred about 1 hour apart in 4 Section of the JWR No. 5 Mine, resulting in 13 deaths [2,3]. Prior to the first explosion, four workers were building supplemental roof support cribs in an area where the mine roof and ribs were deteriorating. A scoop battery charging station was under the bad roof, and next to a stopping separating methane-laden return air from fresh ventilation air. This mine liberated 17.2 million cubic feet of methane per day through the returns and out the mine exhausts. Methane bleeders in the roof and floor were prevalent. The battery charger was placed next to the

Table 1. Fatal methane and methane plus coal dust explosions in US underground coal mines since 1976 linked to nonpermissible electrical equipment in intake air entries.

Year	Operator, mine, and state	Fuel	Ignition location	Possible ignition sources	Killed
1976 (1 of 2)	Scotia Coal Co., Scotia Mine, KY	Methane	Intake	Normal arcing of battery powered locomotive	15
1980	Westmoreland Coal Co., Ferrell #17 Mine, WV	Methane	Intake	Trolley wire powered locomotive	5
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
1987	Double R Coal Co., #1 Mine, VA	Methane & coal dust	Intake	Two power centers, battery charging cable, faulted permissible scoop.	1
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
					45 total

stopping to facilitate battery venting to the return entry. The roof caved in before the supplemental roof supports could be completed. The cave-in damaged the stopping, allowing methane to migrate from the overburden and possibly the return entry onto the battery charging station. The cave-in also damaged a battery enclosure, shorting the battery and igniting the first explosion. Section ventilation controls were damaged by the blast. The four miners were injured in the relatively minor explosion, three of whom were able to escape from 4 Section on a diesel locomotive. The incapacitated miner was injured during the first explosion. The MSHA report suggests the injuries may have been fatal. The 4 Section circuit breaker was tripped to remove power to the section; however a block light traffic control circuit remained energized because it was powered through a breaker located in another mine section.

Within an hour, 12 miners went towards 4 Section to rescue the one remaining incapacitated miner. In the mean time, methane gas had accumulated in 4 Section through the damaged ventilation controls. Some of the rescuers drove the locomotive back into 4 Section. The locomotive ran over and entangled slack electrical cable for the live block light traffic control system. The cable was damaged in several places, exposing energized conductors. Evidence suggests the coworkers reached the injured miner and were bringing him to safety. It is thought that the rescuers may have disturbed the damaged, energized block light cable. Or perhaps one of the miners had shown a caplamp onto a photo-switch in the master or slave block light units that energized a damaged conductor. The spark ignited the second massive explosion, killing all the miners.

III. SELECTED MSHA FINDINGS

MSHA concluded a live high voltage cable hit by the initial roof fall was not a likely ignition source for the first explosion. Resistance measurements indicated the cabling was robust enough to prevent the conductors from being faulted. Even if the cable were faulted, the shielded conductors would have caused a ground fault, activating the protective circuit breaker in less than a second. The ignition did not occur for a few minutes. The robust cabling design and the grounded shielding prevented the live high voltage cable from being an ignition source.

MSHA determined a scoop battery was the likely ignition source for the first explosion. The roof fall damaged the battery assembly such that the steel frame of the battery tray contacted both the negative battery terminal and an intercell connector. The short circuit produced temperatures capable of igniting methane-air mixtures. A permissibility examination was completed for the battery assembly. No significant conflicts in design or construction with the approval documents were noted.

MSHA determined the block light system was the most likely ignition source for the 2nd massive explosion. The system consisted of two nonmetallic NEMA 4X enclosures with three lights and a photocell mounted in each, which were connected by long lengths of cable. The block lights were used to control traffic in a particular section of the mine. A miner would shine his caplamp onto the photocell to activate the traffic control lights in each box before proceeding. Fig. 1 is the block light circuit diagram replicated from the MSHA report appendix CC [2]. The system used 120 V for control signals and to power the lights. The boxes were connected by type SDT, 16 AWG, 12 conductor, unshielded cable. Six conductors were used and 6 were spare. Some conductors were connected to the line voltage and neutral. Fig. 1 shows no separate grounding conductor in the block light cable between the nonmetallic enclosures, or an equipment bonding jumper in the master enclosure for such a grounding conductor. No connections were shown for the spare conductors, suggesting they were not grounded. Usually slack cable connecting the master unit to the slave unit was rolled up and placed behind the slave unit to be unwound as the section, track, and ultimately the slave unit were advanced.

The MSHA report included a section on root cause analysis. This section notes that underground electrical configurations should be reviewed to assure that their design or complexity would not confuse foremen or electricians, and unusual configurations should be made known to all persons working in the area. No enforcement action was taken with regard to the design of the electrical equipment. 30 CFR 75.516-2 (b) indicates that communication cables must be protected against mechanical damage in a manner approved by the Secretary. MSHA did not interpret the block light cable installation as a violation of this requirement. The electrical equipment that provided the ignition sources for the explosions were not required to be permissible while in the intake-air course.

IV. 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] [5]. NEC Article 500 describes Division locations while Article 505 describes Zone locations. 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 [6] and NFPA 499 [7] provide guidelines for classifying Hazardous Locations.

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 [6] provides guidelines for classifying flammable liquids, gases, or vapors.

Class I Division 1 and Zone 1 locations are described in NEC 500.5(B)(1) and 505.5(B)(2). One description is a location in which equipment is operated or processes are carried on, of such a nature that equipment breakdown or faulty operations could result in the release of ignitable concentrations of flammable gas and also cause simultaneous failure of electrical equipment in a mode to cause the electrical equipment to become a source of ignition. A Division 1 or Zone 1 classification would be appropriate where common cause failures could release a flammable material and damage electrical equipment to produce an ignition source. Division 1 protection techniques include those familiar to the mining industry: explosion proof enclosures and two-fault intrinsic safety. 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)).

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) and 505.5(B)(3)). 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 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.

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)). A Class I Zone 2 restricted breathing enclosure, for example, will eventually leak, allowing a flammable concentration of gas to accumulate inside the enclosure if the enclosure is immersed in a flammable atmosphere for a long period of time. Magison [8] analyzes gas diffusion into sealed enclosures for explosion prevention purposes. The hermetically sealed contacts of a vacuum circuit breaker are another example of a sealed enclosure that is not an ignition source under normal

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

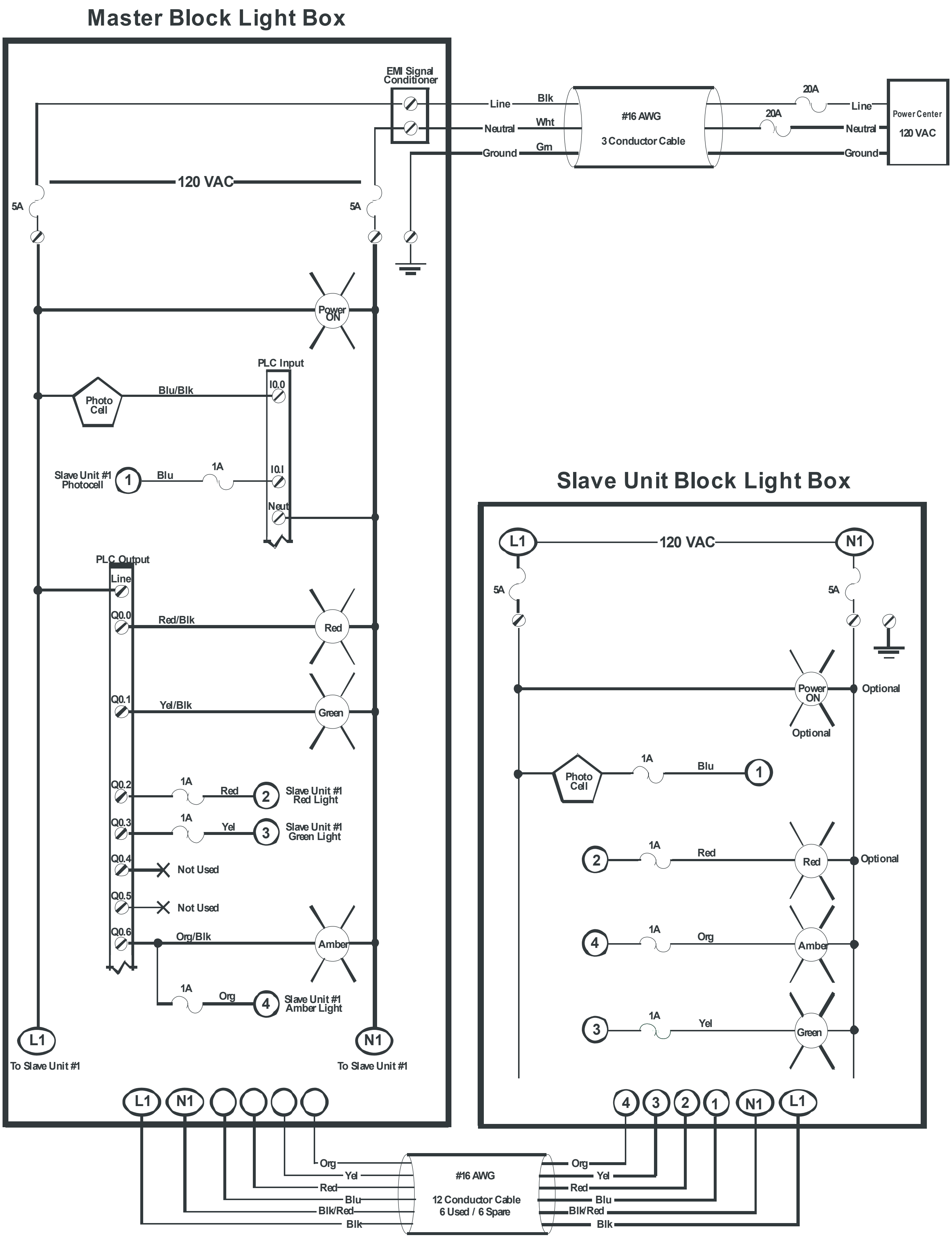

Fig. 1. Block light electrical circuit diagram.

operation. For normal operation of electrical equipment in underground coal mines, an upper limit of the duration the equipment may be exposed to methane can be estimated based on the timing of required periodic methane checks. During emergencies however, battery powered equipment may be abandoned and exposed to methane for an extended period of time. More stringent protection would therefore be necessary for battery powered equipment abandoned during a mine emergency. Magison [8] explains Sealing and several other practices and principles for preventing explosions ignited by electrical equipment.

These descriptions of Divisions and Zones reflect the situation found in intake air courses of gassy underground coal mines ventilated by fresh air where normally sparking electrical equipment is allowed to be used, and which may become flammable when the ventilation system fails. Fatal explosions in intake air courses ignited by electrical equipment have occurred numerous times in the past (Table 1) [1]. Underground mines rely primarily on maintaining adequate ventilation and periodic methane checks to prevent explosions in intake air courses (30 CFR Part 75 Subpart D). 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.

V. BROOKWOOD IGNITION SOURCES ANALYSIS

A. Block light installation

Due to a series of events resulting from a roof fall and loss of ventilation, flammable gas migrated to damaged, slack cable near the block light slave unit, which most likely ignited the fatal second explosion. The flammable gas migrated to the unprotected equipment under infrequent, abnormal conditions when the ventilation system failed. This situation fits the NEC® description of a Class I Division 2 or Zone 2 hazardous location, which 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.

The block light installation apparently did not meet several NEC® requirements for Class I hazardous locations. The installation of long lengths of slack, unsecured block light cable that became entangled and most likely provided the ignition source for the 2nd massive explosion may not have met 1999 NEC 501.11 which states that flexible cord used in a Class I Division 1 or 2 hazardous location is to be protected by location or a suitable guard from damage[2]. Spare conductors in the unshielded block light cable apparently were not grounded. Fig. 1 shows no separate grounding conductor in the block light cable between the nonmetallic enclosures, or an equipment bonding jumper in the master enclosure for such a grounding conductor. The 1999 NEC 501.11 requires flexible cord to contain, in addition to the conductors of the circuit, a grounding conductor. The block light type SDT cable is not listed in NEC Table 400-4 as a type considered acceptable for extra hard usage. The 1999 NEC 501.11 requires flexible cord to be listed for extra hard usage. Robust protection provided by extra hard usage cord jacketing material combined with a grounding conductor and grounded spares inside the cord may have allowed a short to ground to activate the circuit protection fuse before the outer jacketing material was compromised, exposing the conductors to the flammable atmosphere (The 1999 NEC 501-6 provides requirements for fuses in Class I Division 1 and 2.). The live high voltage cable discussed above was determined not to be an ignition source for the first explosion for comparable reasons. Adherence to these NEC® requirements written specifically for preventing explosions may have prevented the massive second Brookwood explosion.

B. Battery assembly

The first explosion involving the battery assembly fits the description of Class I Division 1 or Zone 1, defined as a location in which equipment is operated or processes are carried on, of such a nature that equipment breakdown or faulty operations could result in the release of ignitable concentrations of flammable gas and also cause simultaneous failure of electrical equipment in a mode to cause the electrical equipment to become a source of ignition. The roof fall damaged the ventilation controls, released methane gas, and damaged the battery assembly so as to produce an ignition source. Also, there was no way of deenergizing the battery during the initial emergency, allowing the ignition hazard to persist while methane gas accumulated around the battery. The common cause failures produced by the roof fall and the persistence of the battery ignition hazard over time suggest the battery assembly should have been protected by Division 1 or Zone 1 techniques.

MSHA found no significant problems with the battery assembly linked to the first explosion. 30 CFR Part 7 Subpart C lists federal requirements for battery enclosures. The United Mine Workers of America (UMWA) contend the battery enclosure was not well insulated, even though an insulation option was available from the manufacturer [3]. Following the disaster, the UMWA requested that such insulation be provided. The UMWA also requested installation of rubber conduit on all cables and leads, and support braces for the enclosure to protect the battery from damage from foreseeable roof falls. Extra structural support should take into consideration that manufacturers recommend opening the battery cover during charging to prevent the build-up of explosive hydrogen-air concentrations, and to provide cooling for the cells. The standard for the Zone 1 protection technique "increased safety" calls for sufficient insulation between a battery enclosure and cells to prevent

[2] The 1999 edition of the NEC was the current edition at the time of the Brookwood disaster. NEC clause 501.11 was moved to clause 501.140 in the 2005 edition.

shorting [9]. The 30 CFR Part 7 requirements for battery assemblies should be reevaluated, taking into consideration the UMWA recommendations and "increased safety" requirements for battery assemblies.

The UMWA also requested that gas detectors be placed near a power center and in a fresh air entry. These recommendations are in line with the Division 2 protection technique "Combustible Gas Detection System" called out in NEC 501.7 (K). The UMWA recognized the need to explosion protect equipment in fresh air locations susceptible to fugitive emissions of flammable gas, protections already enjoyed by workers in other industries.

VI. HAZARDOUS LOCATION SURVEY

Babiarz et al [10] conducted a survey of electrical cable vs. conduit usage in hazardous (classified) locations. About 125 U.S. and Canadian electrical professionals responded to the survey. The respondents were employed at oil refineries, chemical plants, pulp and paper mills, or were consultants to these industries. Over 95% of the respondents represented heavy industry with electrical installations in hazardous (classified) locations. The respondents with hazardous (classified) locations reported 90% of their hazardous areas were classified as Division 2, compared to only 5% classified as Division 1. Division 1 protection techniques include those familiar to the mining industry: explosion proof enclosures and two-fault intrinsic safety. This survey demonstrates that Division 2 classified locations are common in North American industries at risk from fugitive emissions of flammable gas, except for underground coal mines.

VII. BROOKWOOD VS. TEXAS CITY DISASTER

Certain aspects of the Brookwood disaster can be compared to the BP refinery explosion in Texas City, TX on March 23, 2005, killing 15 workers [11]. The explosions for both disasters were ignited in locations where flammable gases or vapors occurred infrequently, but were foreseeable, and both fatal explosions were likely ignited by nonpermissible equipment. The possible ignition sources for the BP disaster were in locations probably less likely to be exposed to flammable atmospheres than working sections of gassy underground coal mines. OSHA cited BP North America for 167 *egregious* willful violations for using non-intrinsically safe electrical equipment in these locations. The proposed penalty for these electrical equipment violations alone was over $11 million. Civil lawsuits will likely involve much higher amounts. In contrast, MSHA did not issue any citations or make any recommendations in their root cause analysis with regard to the design of the electrical equipment that ignited both JWR explosions. Subsequently, fines of $435,000 were reduced to $3,000 after an administrative law judge ruled the company's safety violations were minor [12].

VIII. ELECTRICAL REQUIREMENTS FOR SURFACE COAL MINES

Federal mining regulations for surface coal mines and surface work areas of underground coal mines require all wiring and electrical equipment to meet requirements of the NEC® in effect at the time of installation [30 CFR 77.516]. Such wiring and equipment would be subject to NEC® requirements for Division 2 locations, where applicable. Similar provisions are not found in 30 CFR Part 75 for underground coal mines. NEC® explosion protection requirements and techniques for Division 2 are recognized for surface locations of coal mines, but not for underground locations fitting the same criteria.

IX. EMERGENCY SHUT DOWN PROCEDURES

Federal regulations require that electrical power be shut off in an emergency such as occurred at Brookwood (30 CFR 75.323). Mine workers did shut down the electrical power to the section where the second explosion occurred, however, the block light slave unit in the section remained energized for several reasons. Although the power to the section was disconnected, the block light slave unit was powered by a cable from another section. A later communications breakdown prevented the electrical power for the whole mine from being disconnected in time. One lesson from the Brookwood disaster may be that an orderly, manual shutdown of electrical power systems during the chaos of a mine emergency may not be a practical method of preventing explosions ignited by nonpermissible electrical equipment. Also, an unprotected electrical disconnect located near the source of gas release and activated during an emergency could provide the spark to ignite an explosion. Division 2 or Zone 2 protection techniques can provide a critical window of protection before all electrical power is shut down.

X. RISK ASSESSMENT FOR EXPLOSION PROTECTED EQUIPMENT

Although not recognized in the NEC® yet, 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 [13]. 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.

The Instrumentation, Systems, and Automation (ISA) Society SP12 committee for Hazardous Location Equipment includes US Technical Advisory Groups (TAGs) for developing IEC TC 31 standards. The SP 12 committee also works toward US adoption of IEC explosion protected equipment standards. The ISA SP 12 committee recently established a mining working group to address explosion protected mining equipment. US equipment users and manufacturers are encouraged to participate in the process.

XI. RECOMMENDATIONS

The Brookwood disaster and other fatal mine explosions suggest intake air entries of gassy underground coal mines that might become hazardous through failure or abnormal operation of the ventilating system should be considered as certain Hazardous (classified) locations per the NEC®. Class I Division 2 or Zone 2 approved protection techniques should be used for non permissible intake-air electrical equipment that is likely to be de-energized during emergencies. Non permissible intake-air equipment that is likely to remain energized for extended periods during emergencies, such as battery powered equipment, should be protected by Class 1 Division 1 or Zone 1 techniques at a minimum, for the sake of the rescuers. Flexible cords should be installed in accordance with 2005 NEC 501.140. The 30 CFR Part 7 requirements for battery assemblies should be reevaluated, taking into consideration the UMWA recommendations and the Zone 1 "increased safety" standard requirements for battery assemblies. US mining equipment users and manufacturers are encouraged to participate with the ISA SP 12 committee to develop and adopt internationally harmonized guidelines for explosion protected equipment.

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