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In-Mine Evaluation of Smoke Detectors

By G. S. Morrow and C. D. Litton

UNITED STATES DEPARTMENT OF THE INTERIOR

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

fpm	foot per minute	min	minute
m	meter	ppm	part per million
mA	milliampere	V	volt

IN-MINE EVALUATION OF SMOKE DETECTORS

By G. S. Morrow[1] and C. D. Litton[2]

ABSTRACT

This report presents the results of a U.S. Bureau of Mines evaluation of smoke detectors placed in conveyor belt entries of underground coal mines. The selected mines are located in six different Mine Safety and Health Administration (MSHA) districts, are operated by seven different companies, and use atmospheric monitoring systems from seven different manufacturers. Principal concerns are early detection and warning of fires, reliability of operation, frequency of maintenance, and adaptability of detectors to monitoring systems and the mining environment. The data contained in this report provide for some comparisons between smoke detectors and CO sensors, specifically in the areas of early detection of fires and susceptibility to nuisance alarms due to diesel exhaust contaminants. Finally, recommendations for performance standards, sensitivity tests, detector classification, and maintenance are presented.

[1]Electronics technician.
[2]Supervisory physical scientist.
Pittsburgh Research Center, U.S. Bureau of Mines, Pittsburgh, PA.

INTRODUCTION

SELECTION OF DETECTORS

During 1988 and 1989, the U.S. Bureau of Mines conducted an in-depth survey of commercially available smoke detectors to determine which detectors had potential for use in underground coal mines. A major consideration in this analysis was that the detectors either be impervious to dust or have the capability to eliminate dust. Based upon this survey, four candidate smoke detectors were identified. Three use internal pumps to convey a sample of gas to the detecting element for subsequent detection. Such detectors offer the potential for selective aerodynamic filtering of the larger dust particles from the flow. One detector uses a cloud condensation nuclei monitor to measure the number of smoke particles.

The first detector identified was the latter type. The Bureau, in previous research studies with a detector of this type, found that complex valving within the detector was sensitive to even minute dust levels, rendering the detector inoperative. Because of this feature, this particular detector was excluded from further study.

The second detector identified was the VESDA smoke detector, marketed in the United States by Fenwal, Inc., and manufactured in Australia. This type of detector uses a pulsed xenon lamp to measure the light scattered by smoke particles. In general, this type of detector is classified as a photoelectric-type smoke detector.

The third detector identified was the Westinghouse HRD-2A smoke detector, manufactured and sold by the Fire Safety Systems Division of Westinghouse in the Netherlands. This detector measures the current reduction due to smoke particles present in a small ionization chamber and is known generically as an ionization-type smoke detector.

A fourth smoke detector, the Becon Mark IV detector, is also known to be impervious to dust and has been evaluated by the Bureau in previous research.[3] This detector was excluded because it utilizes a nonexempt source of radioactivity.

Nine HRD-2A smoke detectors and one VESDA smoke detector were subsequently purchased by MSHA and the Bureau. The choice of detectors was made primarily on the basis of cost (five HRD-2A detectors cost the same amount as two VESDA detectors).

[3]Pomroy, W. H. Fire Detection Systems for Noncoal Underground Mines. Paper in Recent Developments in Metal and Nonmetal Mine Fire Protection. BuMines IC 9206, 1988, pp. 21-27.

Apart from the method of detection, i.e., photoelectric technique for the VESDA detector versus ionization technique for the HRD-2A detector, the two are similar in appearance and operation. Figures 1, 2, and 3 are photographs of the HRD-2A detector, VESDA detector, and the sampling port used for all detectors, respectively. Both detectors utilize a small dc axial-vane fan to draw air samples from the desired monitoring location to the detector. Both detectors operate on 24 V dc and both have 4- to 20-mA outputs.

From the outset a point should be made that the selection of these smoke detectors was not intended to exclude

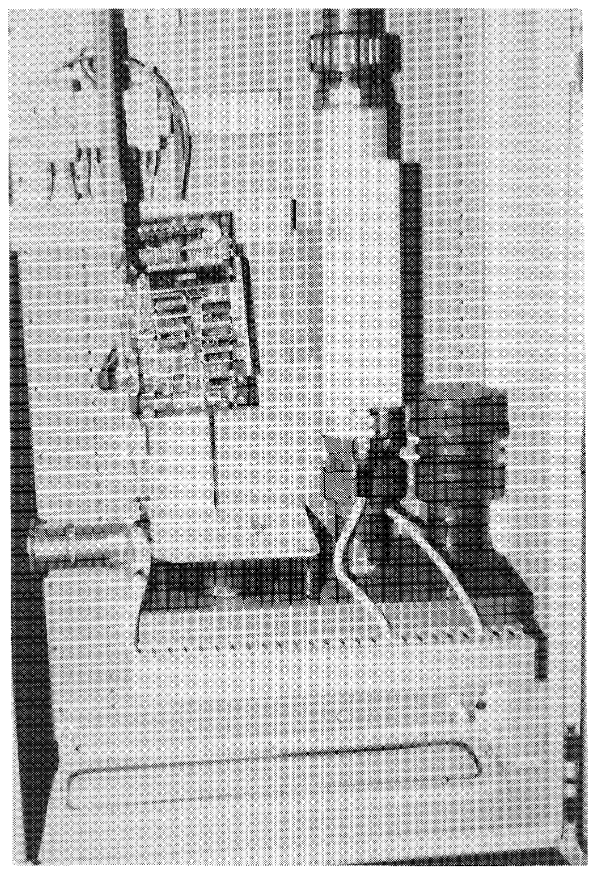

Figure 1.—HRD-2A smoke detector installed at Dilworth Mine.

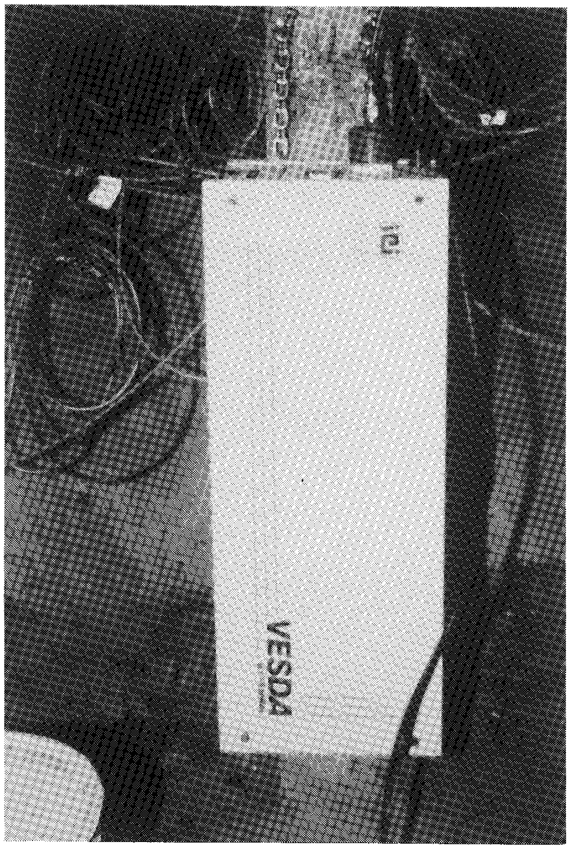

Figure 2.—VESDA smoke detector installed at McClure Mine.

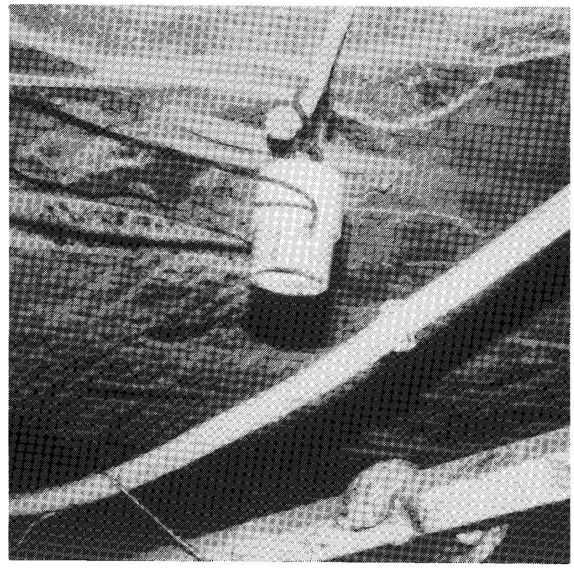

Figure 3.—End-of-line sampling port used at all test sites.

other smoke detectors. The selection of detectors was made on the basis of potential to function reliably in an underground environment. This work was done as part of the Bureau's program to enhance mine safety.

SELECTION OF MINE SITES

Subsequent to the selection of detectors, MSHA and Bureau personnel met to select mines to serve as test sites for evaluation of the detectors. In selecting test sites, three factors were considered. The first factor was accessibility of the mine site to Bureau and MSHA personnel. Although one site in the Western United States was chosen, the remaining sites were in the Eastern United States, in close proximity to the Bureau's Pittsburgh Research Center (PRC). A second factor was the constraint that each mine have in place a CO monitoring system. Additionally, a concentrated effort was made to select mines that used different atmospheric monitoring systems. The rationale for this constraint was that smoke detectors must interface with existing systems and some concern was expressed as to the potential difficulty of providing the appropriate electrical interface from one system to the next. A third factor was to determine whether the detectors were susceptible to false (nuisance) alarms caused by diesel exhaust contaminants, so some mines using diesel-powered equipment were chosen.

Nine mines were identified as test sites. In eight of these mines, a Westinghouse HRD-2A smoke detector was interfaced with the atmospheric monitoring system and installed along the belt entry. In the ninth mine (McClure Mine) both the HRD-2A and the VESDA smoke detectors were installed within the belt entry. This mine was chosen for evaluation of both detectors because it uses diesel-powered equipment, and it was of interest to determine the relative alarm frequency of both detectors to diesel-produced contaminants to see if one detector was less prone to nuisance alarms than the other.

A list of the mine sites chosen and other information for each installation are found in table 1. The dates of installation and removal of the detectors are found in table 2.

Subsequent to the selection of the test sites, MSHA inspectors involved in the test program met for a short training course on the operation of the smoke detectors and the procedures to be followed during each weekly inspection. A standard form was developed for each inspector to complete after each inspection (fig. 4). When the form was completed, it was returned to Bureau personnel and copies were sent to MSHA, Arlington, VA.

Table 1.—Summary of mine test sites and related information

Mine	Owner	System type	MSHA district	Belt air to ventilate face	Diesel equipment used
Cumberland ...	U.S. Steel	Conspec	2	Y	N
Dilworth	Consol	..do	2	N	N
Kopperston ...	Peabody	Femco	4	Y	N
Maple Creek ..	U.S. Steel	MSA........	2	N	N
Martinka	AEP	..do	3	N	N
McClure	Pittston	AMR	5	Y	Y
Scotia	Cumberland ..	Pyott-Boone ..	6	Y	Y
Shoshone	Cyprus	Transmitton ..	9	Y	Y
Splashdam ...	Pittston	Line Power ..	5	Y	N

N No.
Y Yes.

Table 2.—Summary of evaluation periods for detectors at each mine test site

Mine	Weeks in service	Date installed	Date removed	Reason for removal
Cumberland	4	2/ 9/90	3/ 9/90	System power caused fuses to blow in detector and subsequently damaged it.
Dilworth[1]	18	2/ 7/90	6/11/90	Dust buildup. Detector used at Bureau for research
Kopperston:				
Original detector	1	2/15/90	2/22/90	Original failed.
Replacement detector.	13	2/26/90	5/29/90	Replacement removed because of dust buildup. Mine operator ended participation.
Maple Creek	44	2/21/90	12/26/90	End of evaluation.
Martinka	44	3/ 9/90	1/11/91	Do.
McClure[2]	47	2/13/90	1/ 8/91	Do.
Scotia	47	2/12/90	1/ 7/91	Do.
Shoshone	16	4/ 5/90	7/27/90	Removed by company and replaced with CO sensors.
Splashdam	47	2/14/90	1/ 8/91	End of evaluation.

[1]Detector was reinstalled on 10/1/90 and remains functional underground at Dilworth for evaluating methods of reducing false alarms due to rock dust.

[2]Data pertain to both VESDA detector and HRD-2A detector used at this mine.

PROCEDURES FOR INSPECTION AND TESTING OF INSTALLED SMOKE DETECTOR

Mine name:

VISUAL INSPECTION

NOTE: Inform the CO monitoring system operator of your intentions to test the smoke detector.

Damage

Sampling port...YES NO

Sampling tube...YES NO

Detector housing......................................YES NO

Detector-Interface board (if installed)...............YES NO

Comments on damage if so indicated:

Dust at sampling port..........................HEAVY MODERATE LIGHT
(Lightly tap to remove dust)

Operation

Electrical power on?..................................YES *NO
*If no, restore power.

Green light on only?..................................YES *NO
*If no, what combination of lights are on?

RED RED/GREEN YELLOW YELLOW/GREEN

Reset sensitivity by adjusting P1: CCW to eliminate Red, CW to eliminate Yellow.

If it is not possible to restore power and/or reset sensitivity, terminate test and contact Jerry Morrow at (412) 892-4272 or Dave Litton at (412) 892-6752.

Figure 4.—Standard inspection form.

FUNCTION TEST

With housing open and green light visible, introduce smoke to the sampling port. Observe the following:

Green light turns off as red turns on?................YES NO

When smoke clears, observe the following:

Red light turns off as green turns on?................YES NO

If the detector does not respond to the test smoke, yet appears to remain operational, the sampling tube may be blocked. Disconnect the tube at the detector housing and introduce smoke there. If detector responds properly, check sampling tube for blockage. Repeat test to verify proper operation. Terminate test.

If the detector does not respond to smoke at housing inlet, terminate test and contact Jerry Morrow or Dave Litton.

ABOVE GROUND

Return to monitoring station and verify alarm response on computer. Clear alarm.

If alarm was not activated, have system operator check communication to detector and/or alarm threshold levels.

If problem is identified and the system restored to normal operation, describe what was found and what was done.

Obtain from the operator a copy of the past week's alarm printout.

Sign and date this form below and return to Jerry Morrow, U.S. Bureau of Mines, P.O. Box 18070, Pittsburgh, PA 15236, along with the alarm printout. Retain a copy for your records and send an additional copy to Larry Brown, 4015 Wilson Blvd., Arlington, VA 22203.

____________________ Signature

____________________ Date

Figure 4.—Standard inspection form—Continued.

ACKNOWLEDGMENTS

The authors wish to thank Jack Tisdale, chief, Division of Safety, and Larry Brown, safety and health specialist, MSHA, Arlington, VA, for their assistance in selecting mine sites; Ed Miller, chief, Ventilation Division, Bill Francart, supervisory mining engineer, Gary Wirth, mining engineer, John Baron, electronics technician, and Ed Chuhta, mining engineering technician, MSHA (Technical Support), Pittsburgh, PA, for technical assistance at the selected mine sites; and the coal mine inspectors listed in the appendix, who performed the testing of the detectors at each site.

TEST RESULTS

Through January 11, 1991, when all detectors except for the one at Dilworth Mine had been removed, a total of 340 weeks of continuous service had been logged. The total summary of alarms is shown in table 3. If the nuisance alarms due to diesel contaminants are subtracted from the total, then 54 alarms occurred during this study. Of these 54, 20 were found to be real alarms, the result of frictional heatings or frozen idlers that could have developed into a fire. Of the remaining 34 alarms, 11 were the result of rock dusting, 6 were the result of dust accumulation, and 17 were the result of welding and cutting.

These 34 nuisance alarms represent a total average frequency of 0.1 alarms per week (1 alarm every 10 weeks). None of the alarms due to dust accumulation occurred earlier than week 13. It is also worth noting that the air velocities in the mines where dust accumulation alarms occurred were relatively low (50 to 209 fpm).

For the mines using diesel-powered equipment, only the installation at Shoshone Mine allowed a true comparison of the CO levels at the time of smoke alarm. As indicated in the following summary, the number of CO readings may be categorized in terms of exceeding some level of CO. Figure 5 shows the actual CO levels at the time of smoke alarm as discussed above.

The following is a detailed summary of the results of the evaluation at each mine site.

CUMBERLAND MINE

Located near Waynesburg, PA, this mine uses a Conspec atmospheric monitoring system. The point-type heat sensors have been replaced by the monitoring system, and active sections are ventilated with belt air. The CO system has detected several heatings due to faulty belt rollers. The system has not detected a few occurrences of belts rubbing the framework, producing smoke, but little CO.

Table 3.—Summary of smoke detector alarms for each mine test site

Mine	Air velocity, fpm	Rock dusting	Dust accumulation	Welding and cutting	Diesel	Fires, friction, heatings, etc.	Total
Cumberland	170	0	0	0	NAp	0	0
Dilworth	146	2	1	0	NAp	0	3
Kopperston	50	2	1	0	NAp	0	3
Maple Creek	209	0	2	0	NAp	3	5
Martinka	64	0	2	6	NAp	17	25
McClure:							
HRD-2A detector	1,000	2	0	0	486	0	488
VESDA detector	1,000	2	0	0	2	0	4
Scotia	295	3	0	11	1	0	15
Shoshone	180	0	0	0	83	0	83
Splashdam	282	0	0	0	NAp	0	0
Total		11	6	17	572	20	626

NAp Not applicable.

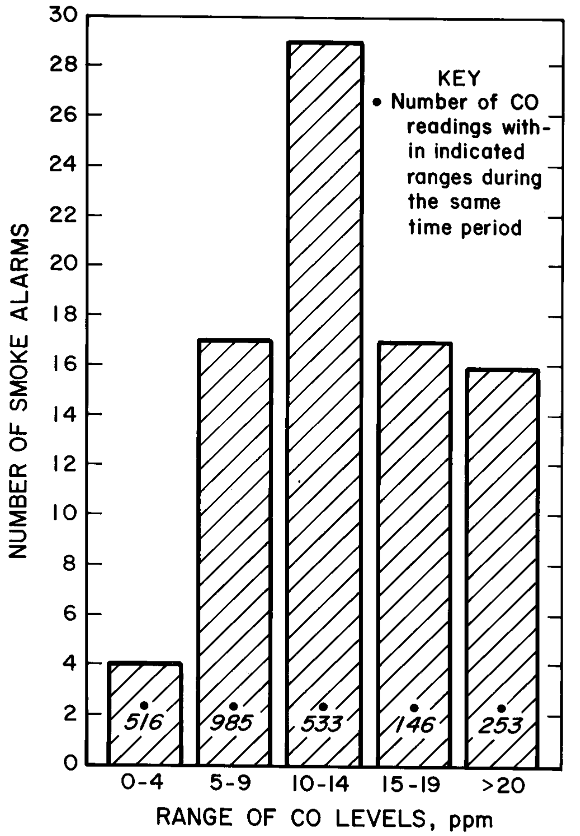

Figure 5.—Smoke detector nuisance alarms versus CO levels for 42-day period at Shoshone Mine.

The smoke detector was installed February 9, 1990, on a main-line belt with three active sections inby the detector location. The air velocity at this location was 170 fpm. Power was obtained from a nearby CO sensor. The detector interfaced with the system via a 4- to 20-mA accessor provided by Conspec. After 2 weeks of operation the detector intermittently alarmed and then failed the following day. Upon inspection, the internal fuse of the detector was found to be blown. The fuse was replaced and the detector was brought back on line. Two weeks later similar indications prior to the fuse being blown resurfaced. The mine was directed to disconnect power to the detector. Attempts were made to schedule troubleshooting to determine the cause of the failures, and later to remove the detector from service. After several attempts to visit the mine, the detector was finally recovered in July 1990. After testing in the laboratory the detector was found to be damaged, possibly by the monitoring system power, to the extent that manufacturer repairs were warranted.

DILWORTH MINE

The Dilworth Mine, located in Rices Landing, PA, uses a Conspec atmospheric monitoring system to monitor CO, belt operations, silo storage, and river levels. The Conspec system supplements a Femco point-type heat sensor system.

The detector was installed February 7, 1990, on a main-line belt entry with an air velocity of 146 fpm. Power was obtained from a nearby CO sensor. The detector interfaced with the system via a 4- to 20-mA accessor provided by Conspec. The detector functioned properly until week 18, when the mine reported intermittent alarms lasting 10 to 20 min, but with no recurring pattern. The detector was removed, cleaned, and monitored continuously on a Conspec system at the Bureau with no alarms recorded. The mine had reported brief alarms from the detector while rock dusting. From July 30, 1990, to reinstallation in the mine on October 1, 1990, the detector was used for research purposes at the Bureau and functioned properly. The addition of a settling chamber on the sampling line, along with the insertion of honeycomb mesh at the end of the sampling tube, reduced but did not eliminate false alarms due to rock dusting. The detector remains in place to further research methods to reduce rock dust alarms.

KOPPERSTON MINE

The Kopperston Mine, located near Kopperston, WV, uses a Femco atmospheric monitoring system. Active sections are ventilated with belt air, and the point-type heat sensors have been replaced with CO sensors. The CO system has detected several instances of hot belt rollers, along with nuisance alarms due to cutting and welding.

The detector was installed February 15, 1990, along a main-line belt outby a longwall section. Air velocity at this point was 50 fpm. The detector did not require any interface to the system. The first inspection revealed a cold solder joint that caused intermittent alarms. The original detector was replaced with a spare in week 2. Intermittent alarming occurred after week 13 of operation. Mine personnel said that often the entry is heavily rock dusted. These alarms were of the same pattern observed at Dilworth Mine. The detector was removed, cleaned, and monitored. The detector was returned to the inspector for reinstallation. The mine requested that it not be reinstalled.

MAPLE CREEK MINE

The Maple Creek Mine, located near Ginger Hill, PA, uses an MSA DAN 6000 atmospheric monitoring system. The CO system has replaced point-type heat sensors. The system has detected CO from a hot gearbox at the face.

The detector was installed February 21, 1990, on a main-line belt outby two continuous mining sections and a longwall section. The air velocity at this location was 209 fpm. Mine power was required to operate a dc power supply for the detector, along with the use of a standard input board supplied by MSA for interfacing to the system.

The detector alarmed at or about 15:25 on April 18, 19, and 20. Initially the reason was not known. On April 20, miners were in the vicinity of the detector when it alarmed. They discovered that the belt was producing smoke while rubbing the framework when empty and out of alignment. Intermittent alarming attributed to rock dusting occurred during week 18 of operation. The inspector cleaned the detector on-site. The detector continued to operate normally until December 25, 1990, when it again alarmed intermittently. These alarms again were due to a buildup of rock dust, primarily in the sampling line.

MARTINKA MINE

The Martinka Mine, located in Fairmont, WV, uses an MSA DAN atmospheric monitoring system that includes approximately 100 CO sensors along belt entries. The CO sensors have replaced point-type heat sensors. The system has detected three small fires, but failed to detect two other fires.

The smoke detector was installed March 9, 1990, outby No. 18 left belt drive. Mine power was required to operate a dc power supply, and the detector interfaced with the system via a voltage-to-frequency board supplied by the Bureau. Air velocity at this location was 64 fpm.

During the 44 weeks the detector was in operation, several alarms occurred because of belts rubbing or overheated rollers. On June 12, 1990, the detector alarmed, causing the mine to place all section crews in intake air, initiating evacuation procedures. A hot roller was discovered to be smoking. A CO sensor adjacent to the smoke detector showed no response. The mine based its decision to treat the smoke alarm as real, even though no CO was detected, on the fact that previous smoke alarms had occurred on June 9, 1990, due to cutting and welding, again without detection by CO sensors. On June 13 and 14, 1990, the detector alarmed because of a rubbing belt, with no CO indications. The mine found four rollers frozen on the take-up. On June 15, 1990, evacuation of five crews was initiated because of smoke detection of a hot roller, again with no CO readings on the adjacent CO sensor. In all, there were 25 smoke alarms recorded on printouts: 17 were due to belts or rollers, 6 were attributed to cutting and welding, and 2 were intermittent (dust accumulation).

McCLURE MINE

The McClure Mine, located in McClure, VA, uses an American Mine Research atmospheric monitoring system. The monitoring system has replaced point-type heat sensors, and the mine uses belt air to ventilate active sections. The mine uses diesel equipment for haulage and transportation in the same entry as the belt. As a consequence, diesel emissions cause some CO alarms. The system has not detected CO in the presence of smoke in the belt entry.

Two detectors were installed on February 13, 1990, along a main-line belt. Air velocity at this location was 690 fpm at the time of installation, and increased to 1,000 fpm during the test period. Both detectors interfaced directly to the monitoring system, although the VESDA detector required mine power to operate a dc power supply.

During 47 weeks of operation the HRD-2A detector alarmed 488 times and the VESDA detector alarmed 4 times. Diesel contaminants accounted for 486 alarms on the HRD-2A detector and 2 on the VESDA detector. Rock dusting caused two concurrent alarms on both smoke detectors.

On average, the nuisance alarm frequency due to diesel exhausts was about three alarms every 2 days. This frequency is about 25% lower than the frequency observed at the Shoshone Mine, where diesel equipment is also used.

SCOTIA MINE

The Scotia Mine, located near Ovenfork, KY, uses a Pyott-Boone atmospheric monitoring system. The CO system has replaced point-type heat sensors, and the mine uses belt air to ventilate active sections. Diesels are used at the mine, but track and belt are located in different, separated entries. The mine has had a fire that went undetected by the CO system.

The smoke detector was installed February 12, 1990, on a main-line belt. Air velocity at the location was 295 fpm. Mine power was required to operate a dc power supply for the detector. At the time of installation the Pyott-Boone system could not accept the 4- to 20-mA signal from the detector. On April 2, 1990, Pyott-Boone developed and installed interface circuitry and modified its software to allow for aboveground monitoring of the detector.

During the 47 weeks of operation, the detector alarmed 15 times. Cutting and welding caused 11 alarms, with concurrent CO readings of 10 ppm 3 of the 11 times. One alarm occurred because of diesel emissions, and three brief alarms occurred as the entry was being rock dusted.

SHOSHONE MINE

The Shoshone Mine, located near Hanna, WY, uses a Transmitton atmospheric monitoring system. The CO system supplements point-type heat detectors. The mine uses diesel equipment, and employs a two-entry longwall development system for some of its sections.

The detector was installed April 5, 1990, in a two-entry section in the belt entry return air. Eighty-three alarms occurred during the period of April 28, 1990, through June 9, 1990 (42 days); all were attributed to diesel emissions. During the same period, a companion CO sensor had 516 readings of 0 to 4 ppm, 985 readings of 5 to 9 ppm, 533 readings of 10 to 14 ppm, 146 readings of 15 to 19 ppm, and 253 readings in excess of 20 ppm.

These smoke detector alarms and CO levels due to diesel exhaust allow for a direct comparison of the nuisance alarm frequency for the two types of detectors. For the smoke detector, this alarm frequency is about two per day. For CO at the 10-ppm level, the alarm frequency is 22 per day. For CO at the 15-ppm level, the alarm frequency is 10 per day. At the 20-ppm CO level, the alarm frequency is still six per day, or three times greater than the alarm frequency for the smoke detector.

While the absolute number of nuisance alarms due to diesel emissions appears high, as it was for the smoke detector at McClure Mine, the actual alarm frequency is significantly lower than that of CO sensors. It should also be noted that the smoke detector continuously operated at its maximum level of sensitivity, thus increasing its potential to respond to diesel contaminants. At this level of sensitivity, the equivalent CO detection level from a small coal fire is typically in the range of 3 to 5 ppm. As a result, the smoke alarm frequency should be compared with the CO alarm frequency at the CO level of 5 ppm. If this comparison is made, then the 5-ppm CO alarm frequency was 46 per day, or 23 times greater than the smoke alarm frequency.

Even though the nuisance alarms are not eliminated, their frequency is reduced significantly. It is possible that by decreasing the smoke detector sensitivity by a small amount, these alarms could be reduced even further.

In general, the smoke alarms correlated with significant increases in the CO levels. With the exception of two alarms on May 2, 1990, and May 4, 1990, the average CO reading at the time of the smoke alarm ranged from a low of 3 ppm to a high of 34 ppm, with the average level being 17 ppm. On June 9, 1990, the sampling tube was moved into intake air and the alarms ceased. On July 27, 1990, the operator decided to remove the detector from the mine, could not be convinced to relocate it in the mine, and returned it to the Bureau.

SPLASHDAM MINE

The Splashdam Mine, located near Haysi, VA, uses a Line Power Manufacturing atmospheric monitoring system. The system has replaced point-type heat sensors, and the mine ventilates active sections with belt air. The system has detected some small fires and heatings in the past.

The detector was installed February 14, 1990, on a main-line belt that shares the entry with the track (electric trolley). Air velocity at the location was 282 fpm. No alarms occurred during 47 weeks of operation. The sampling line had to be cleaned once because of buildup of rock dust.

The principal concerns mentioned in the abstract—early detection and warning of fire, reliability of operation, frequency of maintenance, and adaptability to monitoring systems and the mining environment—were successfully evaluated. All detectors easily interfaced with existing monitoring systems. Adherence to a maintenance schedule suggested in the Conclusions and Recommendations sections of this report will ensure successful operation of detectors in the mining environment. The ability of the detectors to provide early detection and warning of fire was proven at the Martinka and Maple Creek Mines, where friction-induced smoke from belts and rollers was detected without the presence of CO. Finally, considering that these particular detectors were not designed for the harsh environment of a coal mine, the overall reliability of operation was excellent.

CONCLUSIONS

The final results are presented in terms of the type of problem encountered.

Electrical and Electronic. Aside from some initial problems in trying to interface the detectors with the existing atmospheric monitoring systems, no major electrical or electronic problems were encountered that were attributed to the detectors. The detector installed at Cumberland Mine was thought to be damaged by the monitoring system power.

Alarms. Several instances were noted where the detectors discovered heatings along the belt in some form or other. Aside from the diesel alarms, the primary sources of false alarms were rock dusting (11 total), dust accumulation (6 total), and cutting and welding (17 total). The fact that alarms occurred during rock dusting implies that some method should be found to eliminate or reduce the dust transported to the detector. This would eliminate such alarms and tend to reduce subsequent alarms that occur because of buildup of dust. Further, routine maintenance and cleaning of the detector head at intervals of about 8 to 10 weeks should eliminate alarms due to dust accumulations, and are recommended for future smoke detector installations.

The HRD-2A smoke detector experienced several alarms due to diesel-powered equipment emissions. Although alarms did occur, the frequency of alarms was less than that of CO sensors (see figure 5 and Shoshone Mine summary). The alarm rate of the VESDA detector to diesel exhaust contaminants was much lower, which is most likely due to the principle of operation of this device. Diesel particles have small diameters and their scattering efficiency is significantly less than that of fire smoke particles. Photoelectric-type smoke detectors may have significant potential for use in mines with diesel-powered equipment, because these detectors are less sensitive to diesel particulate matter, but this aspect of fire detection needs to be further validated.

RECOMMENDATIONS

Based upon the results of these studies, the following recommendations are made regarding performance standards for use of smoke detectors in underground coal mines.

1. No smoke detector should be used unless it has been approved by MSHA according to performance standards. In the United States, both Underwriters Laboratories, Inc.[4] and Factory Mutual Research Corp.[5] have standard approval tests for smoke detectors. In addition to sensitivity testing, smoke detectors that have been approved have also undergone rigorous testing for reliability and should perform well in most applications. The results of this evaluation support that conclusion.

2. A performance test should be designed to determine the detector's sensitivity to both smoldering coal and small, flaming coal fires. This test should be added since no other laboratory performs this testing, yet most underground mine fires typically involve coal at some stage in their development. The test should follow a standard sensitivity test in a well-defined smoke box, such as the one described by Underwriters Laboratories.[6]

Further, it is recommended that the results of these additional tests be used to place smoke detectors in a two-tier classification. The first tier, class 1, would represent smoke detectors that always respond at smoke optical densities of less than 0.022 m^{-1}. The second tier, class 2, would represent smoke detectors that always respond at smoke optical densities of less than 0.044 m^{-1}. If a smoke detector responds at optical densities of less than 0.022 m^{-1} in 100% of the tests it becomes a class 1 detector. If a smoke detector responds at optical densities of less than 0.044 m^{-1} in 100% of the tests, independent of the number of times it responds at 0.022 m^{-1} or less, it becomes a class 2 detector. Any smoke detector that does not respond at an optical density of less than 0.044 m^{-1} in 100% of the tests fails and cannot be approved for use in underground coal mines. The values chosen represent one-fifth

[4]Underwriters Laboratories, Inc. Smoke Detectors for Fire Protective Signalling Systems. Standard for Safety, UL268, February 1986, pp. 23-32.

[5]Factory Mutual Research. Smoke Activated Detectors for Automatic Fire Alarm Signalling. Approval Standard 3230-3250, February 1976, 5 pp.

[6]Work cited in footnote 4.

(0.044) and one-tenth (0.022) of the critical level for visibility (0.22 m^{-1}) discussed by Jin.[7] Alarm levels at greater optical densities could degrade the potential for escape.

3. Some method should be developed to ascertain whether or not the detector is sensitive to dust. This could take the form of a standard test, or it could be a technical decision based upon the operational characteristics of the detector.

4. A reasonable testing and maintenance schedule should be designed for smoke detectors. Based upon the data acquired in this study, an inspection and functional test of the detectors should occur at intervals of 2 to 4 weeks. Periodic maintenance, which would include cleaning the detector head, should occur at intervals of 8 to 10 weeks. A log of inspections and maintenance should be kept and documented.

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[7]Jin, J. Studies of Emotional Instability in Smoke From Fires. J. Fire and Flammability, v. 12, April 1981, pp. 130-142.

APPENDIX.—LIST OF PARTICIPATING MSHA COAL MINE INSPECTORS

Inspector	*MSHA District*	*Mine*
Joseph R. Karpinsky Clarence D. Moats Barry L. Mylan Bill Wilson Tom Woods	2	Cumberland
Walter S. Daniel Ronald E. Hixson Eugene A. Kelly Joseph R. Koscho	2	Dilworth
William R. Brown Stephen M. Dubovich John H. Mull Alvin Shade Francis Wehr	2	Maple Creek
Virgil F. Brown Paul M. Hall	3	Martinka
James F. Bowman Larry E. Cook Michael T. Dickerson Kenny Southern	4	Kopperston
Mattie R. Beaty Roy Davidson Vearl Hileman Michael L. Jackson John Wampler	5	McClure
James A. Baker Roy Davidson Michael L. Jackson Charles F. Reece	5	Splashdam
Tom Engle Norman G. Page Diamond R. Waddles	6	Scotia
Bill Matekovic John Thompson	9	Shoshone