IC 9264

PB91-110809

BUREAU OF MINES
INFORMATION CIRCULAR/1990

Preventing Automatic Fire Suppression System Failures on Underground Mining Belt Conveyors

By Steven G. Grannes, Mark A. Ackerson,
and Garry R. Green

U.S. BUREAU OF MINES
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50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. BuMines IC 9264	2.	3. PB91-110809
4. Title and Subtitle Preventing Automatic Fire Suppression System Failures on Underground Mining Belt Conveyors.			5. Report Date 1990
			6.
7. Author(s) Steven G. Grannes, Mark A. Ackerson, Garry Green			8. Performing Organization Rept. No.
9. Performing Organization Name and Address U.S. Bureau of Mines, Twin Cities Research Center, 5629 Minnehaha Avenue South, Minneapolis, MN 55417			10. Project/Task/Work Unit No. TC-89-48
			11. Contract(C) or Grant(G) No. (C) (G)
12. Sponsoring Organization Name and Address U.S. Bureau of Mines, Washington, DC 20241			13. Type of Report & Period Covered Bureau of Mines Information Circular
			14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

This Bureau of Mines publication summarizes federal mandatory belt conveyor automatic fire suppression system installation requirements and inspection procedures, identifies system failure modes observed during in-mine investigations, and suggests system design and maintenance upgrades which, if implemented, would result in an improvement in overall system reliability. This report is a compilation of recommendations based on discussions with MSHA inspectors, review of manufacturer's literature, discussions with mine personnel, and research investigations of automatic fire suppression system performance in the laboratory at mines. The Code of Federal Regulations (CFR) requirements for installation, inspection, and maintenance of fire suppression systems should be regarded as minimum standards.

17. Document Analysis a. Descriptors

Fire Suppression Reliability

b. Identifiers/Open-Ended Terms

Automatic Sprinklers; Water Deluge; Dry Chemical; High Expansion Foam

c. COSATI Field/Group 13. L

18. Availability Statement Release Unlimited by NTIS	19. Security Class (This Report) Unclassified	21. No. of Pages 26
	20. Security Class (This Page) Unclassified	22. Price

(See ANSI–Z39.18) See Instructions on Reverse OPTIONAL FORM 272 (4–77) (Formerly NTIS–35) Department of Commerce

i-a.

Information Circular 9264

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UNITED STATES DEPARTMENT OF THE INTERIOR
Manuel Lujan, Jr., Secretary

BUREAU OF MINES
T S Ary, Director

i.6

Library of Congress Cataloging in Publication Data:

Grannes, S. G. (Steven G.)
Preventing automatic fire suppression system failures on underground mining belt conveyors / by Steven G. Grannes, Mark A. Ackerson, and Garry R. Green.

p. cm. - (Bureau of Mines information circular; 9264)

Includes bibliographical references: (p. 18)

Supt. of Docs. no.: I 28.27:9264.

1. Mine fires-Prevention and control. 2. Conveying machinery-Fires and fire prevention. I. Ackerson, Mark A. II. Green, Garry R. III. Title. IV. Series: Information circular (United States. Bureau of Mines); 9264.

TN295.U4 [TN315] 622 s-dc20 [622'.82] 89-20985 CIP

i.d

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

A	ampere	pct	percent
gal/min	gallon per minute	psi	pound (force) per square inch
ft	foot	V	volt
ft^3/min	cubic foot per minute	W	watt
min	minute		

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PREVENTING AUTOMATIC FIRE SUPPRESSION SYSTEM FAILURES ON UNDERGROUND MINING BELT CONVEYORS

By Steven G. Grannes,[1] Mark A. Ackerson,[2] and Garry R. Green[3]

ABSTRACT

This U.S. Bureau of Mines report summarizes Federal mandatory belt conveyor automatic fire suppression system installation requirements and inspection procedures, identifies system failure modes observed during in-mine investigations, and suggests system design and maintenance upgrades which, if implemented, would result in an improvement in overall system reliability. This report is a compilation of recommendations based on discussions with Mine Safety and Health Administration (MSHA) inspectors, review of manufacturer's literature, discussions with mine personnel, and research investigations of automatic fire suppression system performance in the laboratory and in mines. The Code of Federal Regulations (CFR) requirements for installation, inspection, and maintenance of fire suppression systems should be regarded as minimum standards.

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INTRODUCTION

Fire protection is achieved by prevention, early detection, and planned fire fighting response. Automatic fire suppression systems are one form of planned fire fighting response, and when properly designed, installed, and maintained in a reliable condition, they can effectively control fires (*1*).[4]

The types of automatic fire suppression systems discussed in this U.S. Bureau of Mines report include: (1) automatic sprinklers, (2) water deluge systems, (3) dry chemical systems, and (4) high expansion foam systems. Two general types of system failure can occur: random failures and wear out failures. Typical random fire suppression failures can be averted by a combination of reliable design and frequent inspections. Typical wear out failures can be averted with predictive diagnostics. Limited field testing of six electronically controlled fire suppression systems resulted in three being predictively diagnosed to have intermittent or impending failure conditions. Two of the three failures were caused by rock dust contaminated relay points. This report recommends that system component failures should prompt a corrective action process whereby the component is repaired, and the inspection process is changed to more readily identify related failure types. This report also recommends written records be kept, which should include defects as well as corrective action.

Fire suppression system failures will inevitably occur in mining due to humidity, dust, chemicals, and the dynamic movement of miners, machines, and material. Automatic fire suppression system designs should therefore be reliable and facilitate easy and accurate inspections. Ideally, inspection and testing provisions should be incorporated into system designs.

Conveyor fires account for about 15 pct of underground mine fires (*2-5*) even though there are extensive Federal safety regulations covering conveyor fire prevention and control. These regulations address drive slip switches, sequence controls, fire resistant belt materials, automatic fire suppression systems, detection and warning systems, and firehose requirements.

While investigating the conveyor fire suppression problem, the Bureau identified automatic fire suppression system reliability (*6*) as a particularly serious deficiency within the mining industry. The objective of this research was to develop and test methods for predictive diagnostic inspections of these systems. In addition to describing the results of this research, this report is a compilation of recommendations for inspection, testing, and maintenance practices for automatic fire suppression systems on conveyor belt drives, which when implemented will achieve a stated level of system reliability.

Fire protection requirements for underground metal-nonmetal and underground coal mines are described in 30 CFR 57C and 75L (*7-8*), respectively. These requirements describe fire protection equipment for various locations as well as inspection and maintenance practices.

Fire protection requirements have been established for these underground locations because of the potential for the start and spread of fire and the restricted personnel egress in a fire situation. Belt conveyor systems are potentially dangerous because of the high-fire incidence rate, high temperatures, dense smoke, toxic gases, and rapid flame spread rate (*9-10*).

Figure 1 shows potentially combustible components of a belt drive system in a typical underground coal mine. These components include electric motors and wiring, lubricating fluids, conveyor belt, and coal. A haze existed above the center drive pulleys which is smoke caused by frictional heating of the belt due to misalignment. This condition was observed by the authors while collecting fire suppression system data.

Specific requirements for automatic fire suppression at main and secondary belt drives in underground coal mines are covered in 30 CFR 75.1101 through 75.1101-22. The suppression system may be a water-deluge type spray system, a foam generator system, a water sprinkler system, or a dry powder chemical system. This protection is in addition to the requirement that waterlines with hose and outlets be installed parallel to all belt conveyors (30 CFR 75.1100-2b). The general requirement for each of these automatic systems is that the belt drive and the first 50 ft of fire resistant belt be protected, or the first 150 ft of nonfire resistant belt be protected. Automatic fire suppression devices are also required on unattended underground (powered) equipment other than conveyors (30 CFR 75.1107). Stephan (*11*) describes fire suppression device requirements for these other types of equipment.

Fire protection in underground metal-nonmetal mines is required on underground belt conveyors at the head, tail, drive, and takeup pulleys (30 CFR 57.4263). It is also required that provisions be made for extinguishing fires along the beltline. Fire protection shall be of a type and size that can extinguish in early stages the classes of fire that could occur. This fire protection may include automatic fire suppression systems. General fire protection requirements are covered in 30 CFR 57C. Appendix I of this subpart lists specific national consensus standards for fire protection and control.

[4]Italic numbers in parentheses refer to items in the list of references at the end of this report.

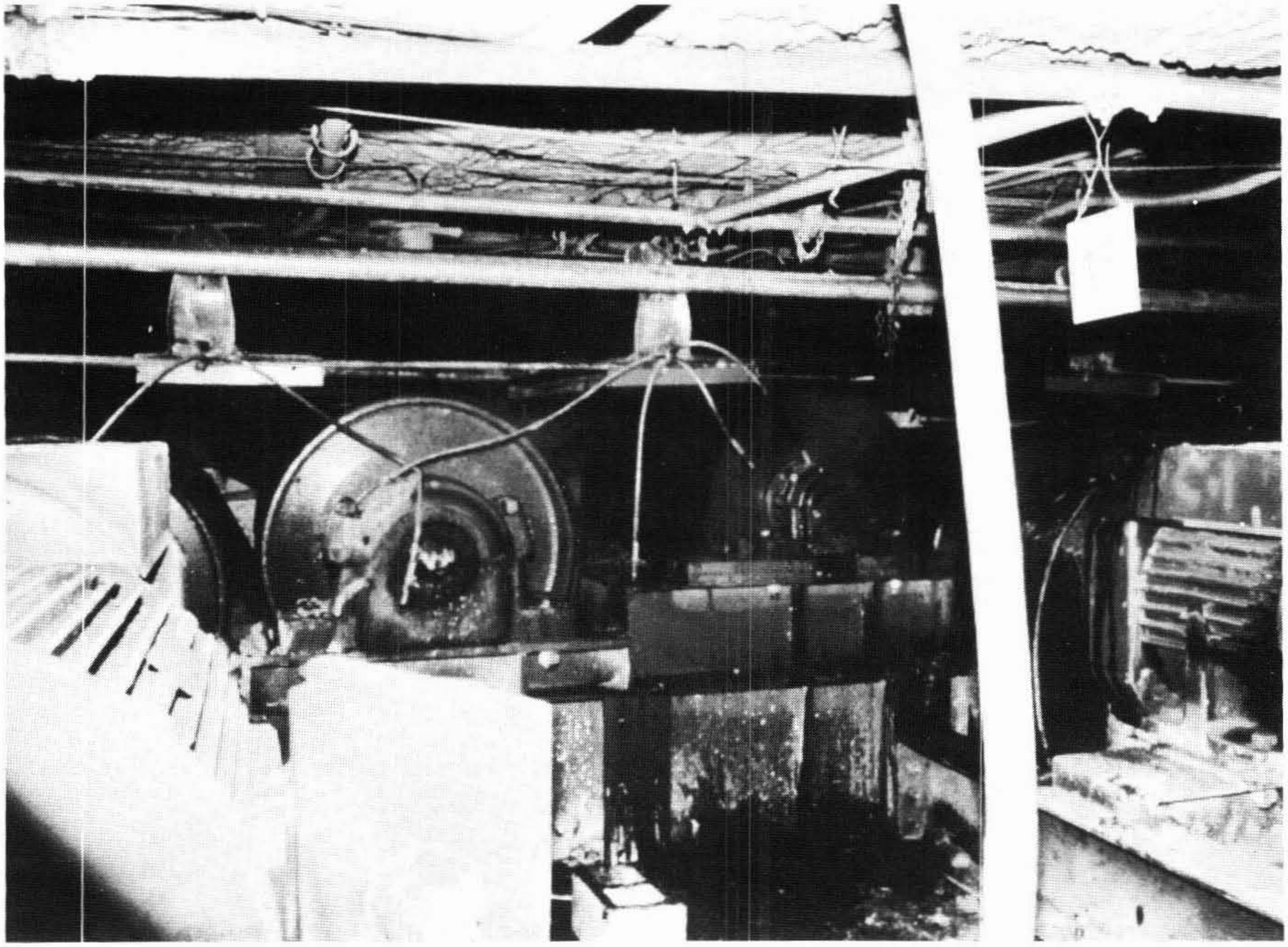

Figure 1.–Conveyor belt drive unit.

Water deluge, dry chemical, and high expansion foam systems are fixed coverage type systems actuated by a mechanical or electrical valve in response to a fire detector. Fixed coverage type systems are designed to contain fires by dispersing a suppressant agent throughout a predetermined area, such as the drive area and the required 50 ft of belt adjacent to the drive. Electronically actuated water deluge systems are the most common systems for belt drive protection (fig. 2). Automatic sprinkler systems are also common, and can effectively protect larger areas because only a few nozzles open at a time in response to heat or flame. For this reason, automatic sprinklers can be used to protect entire belt flights, although this is not a requirement.

Automatic fire suppression systems for belt conveyors should rapidly shutoff the conveyor drive to prevent the moving belt from spreading the fire out of the area covered by the suppression system. In fixed coverage systems, this shutoff is accomplished by flame or heat detectors as part of the suppression control circuit. In automatic sprinkler systems, a flow activated relay can be used to shutoff the belt drive power.

Fire warning systems are an integral part of the suppression function on conveyor systems. In underground coal mining, it is a requirement that these systems provide both an audible and visual warning, and provide identification of fire location to within one belt flight. This fire warning system can also be used to actuate automatic suppression systems (30 CFR 75.1103).

Figure 2.–Functional test of water deluge system on conveyor drive.

MSHA REQUIREMENTS FOR CONVEYOR FIRE SUPPRESSION SYSTEM MAINTENANCE

Automatic fire suppression system inspection and maintenance requirements are specified for both underground coal as well as metal-nonmetal mines in the CFR. Several National Fire Protection Association's (NFPA) National Fire Codes are also incorporated by reference. The purpose of these requirements is to ensure that automatic systems function properly if a fire occurs. In the following sections, various CFR regulations and NFPA standards are summarized. The reader is cautioned that these summaries are provided for illustrative purposes only. They do not comprise the complete texts of these regulations and standards, and should therefore not be used for compliance purposes. Reference to source documents is strongly recommended.

UNDERGROUND COAL MINES

Inspection, maintenance, and testing requirements for fire suppression systems in underground coal mines are contained in 30 CFR sections 75.1100-3, 75.1101-11, 75.1101-22, 75.1107-16. These are summarized in the following list:

All fire fighting equipment shall be maintained in a usable and operative condition (75.1100-3).

Belt drive water sprinkler systems shall be examined weekly, and a functional test of the complete system shall be conducted each year (75.1101-11).

Belt drive dry powder chemical systems shall be examined weekly and a functional test of the complete system shall be conducted each year (75.1101-22a).

All fire suppression systems shall be visually inspected at least once each week by a qualified person (75.1107-16a).

Sections 75.1107-16 (b,c) of 30 CFR require that the testing and maintenance requirements specified in appropriate NFPA National Fire Codes (*12*) be followed, and that written records of these inspections be kept. The fire codes listed in table 1 are incorporated into 30 CFR by reference. These codes specify that manufacturer's testing and maintenance guidelines be followed in addition to specific maintenance procedures for various suppression system types. NFPA 13A "Recommended Practice for the Inspection, Testing, and Maintenance of Sprinkler Systems" provides a guideline for the development of an inspection and testing plan. Belt conveyor drive protection specifications are found in NFPA 15 "Water Spray Fixed Systems for Fire Protection." The NFPA periodic testing and maintenance recommendations for water deluge spray systems are summarized as follows:

Systems shall be serviced and tested periodically by personnel trained in this work. An inspection contract with a qualified agency for service, testing, and operation is recommended (6-1.1).

Operating and maintenance instructions shall be available. Selected personnel shall be trained and assigned to equipment operation and maintenance (6-1.2).

At weekly, or other frequent intervals, equipment shall be visually checked for obvious defects such as missing or broken parts (6-1.3).

Precautions shall be taken to assure water supplies are turned on. Strainers cleaned annually and tested after each system use. Flow tests shall be made each year (6-2.1, 6-2.2).

Piping shall be examined regularly, flow tests should be made yearly or more often as experience indicates (6-2.3, 6-2.4).

Control valves and automatic detection equipment shall be tested at least annually by qualified personnel. Flammable gas detection equipment shall be tested and calibrated at least quarterly by qualified personnel (6-2.5).

Manual valves should be operated at least annually. Flow tests shall be made to insure normally open valves are reopened after tests (6-2.6, 6-2.7).

Nozzles shall be inspected and tested every 12 months for corrosion or clogging. Screens should be checked after each operation for clogging (6-2.8). Systems should be flushed or flow tested annually (6-2.9).

Table 1.–National Fire Codes incorporated by reference in 30 CFR 75

Code and Year	*Title*
NFPA 11A, 1970	High Expansion Foam Systems.
NFPA 13A, 1968-69 ..	Care and Maintenance of Sprinkler Systems.
NFPA 15, 1969	Water Spray Fixed Systems for Fire Protection.
NFPA 17, 1969	Dry Chemical Extinguishing Systems.
NFPA 72A, 1967	Local Protective Signaling Systems.
NFPA 198, 1969	Care of Fire Hose.

UNDERGROUND METAL–NONMETAL MINES

The inspection and maintenance practices pertaining to automatic fire suppression systems protecting conveyor belt drives in underground metal-nonmetal mines are specified in 30 CFR 57.4201 (a,b). These sections are summarized as follows:

Fire extinguisher vessels shall be hydrostatically tested on a 5- to 12-year test interval (depending on type) (57.4201 a3).

Water pipes, valves, outlets, hydrants, and hoses that are part of the mine's fire fighting plan shall be visually inspected at least once every 3 months for damage or deterioration and use-tested at least once every 12 months to determine that they remain functional (57.4201 a4).

Fire suppression systems shall be inspected at least once every 12 months (57.4201 a5).

An inspection schedule based on manufacturer's specifications or the equivalent shall be established for individual components of a system and followed to determine that the system remains functional (57.4201 a5).

At the completion of each inspection or test, the person making the inspection or test shall write a certification of completion with the completion date (57.4201 b).

Hydrostatic certifications shall be retained until retesting is performed, other certifications shall be retained for 1 year (57.4201 b).

AUTOMATIC FIRE SUPPRESSION SYSTEM FAILURE MODES

Automatic fire suppression systems must function correctly. If a fire occurs, there likely would not be adequate time to repair a nonfunctional system. Manual override controls are usually provided, but no one may be present to actuate them. The effectiveness of secondary fire control methods such as hoselines are compromised by smoke, heat, toxic gasses, and rapid flame advance associated with belt fires. Failure prevention for automatic suppression systems is therefore essential.

GENERIC FAILURE TYPES

There are two general types of system failures which can occur: wear out failures and random failures. Wear out failures are characterized by slowly developing performance decrements. Examples of wear out failures include gradual loss of battery power due to chemical action and internal resistance, gradual increase in electrical contact-point resistance due to corrosion or dust buildup, and stuck valves due to corrosion and buildups of mineral deposits.

Wear out related system failures occur when components degrade sufficiently that they can no longer perform their intended function. Wear out failures are predictable and preventable if the performance decrement can be measured, if a system failure linked to the wear out can be anticipated before it occurs, and if appropriate remedial action can be taken prior to the failure event.

Figure 3 is a depiction of this process using a hypothetical electrically operated water valve actuator as an example. Over time, battery voltage would decrease due to battery internal resistance. At the same time, a buildup of corrosion within both the water valve and actuator assemblies would cause the water valve actuator to become gradually more and more sticky. The result would be a steadily decreasing battery voltage and steadily increasing voltage needed to operate the water valve. As long as the battery voltage is greater than the water valve actuation voltage, the system will function properly. Even before the warning level is reached, measurements of these parameters clearly indicate the eventual convergence of battery voltage and actuation voltage. After the warning level is reached, it is apparent that the rate of convergence is accelerating and that appropriate remedial action would be needed, such as replacing the battery and/or cleaning the actuator.

The smooth curves shown in figure 3 are idealized and that due to the nature of the parameters and measurement techniques, actual data would exhibit considerable variance. In a mine setting where only a few measurements would be taken over relatively long time intervals, the data would probably show a great deal of scatter about the idealized voltage curves.

This fact is highly significant, especially as the upper and lower voltage curves get closer together. Although the figure shows that battery voltage and actuation voltage intersect at a discrete time, it is likely, given the variability of individual measurements, that failures will occur intermittently around the average time of system failure. Even in the region to the left of the intersection, the system will occasionally not function.

This possibility is significant because it illustrates the pitfalls of go-no go testing. Go-no go testing involves operation of a system or device as a means for judging its functional readiness. If the device or system functions

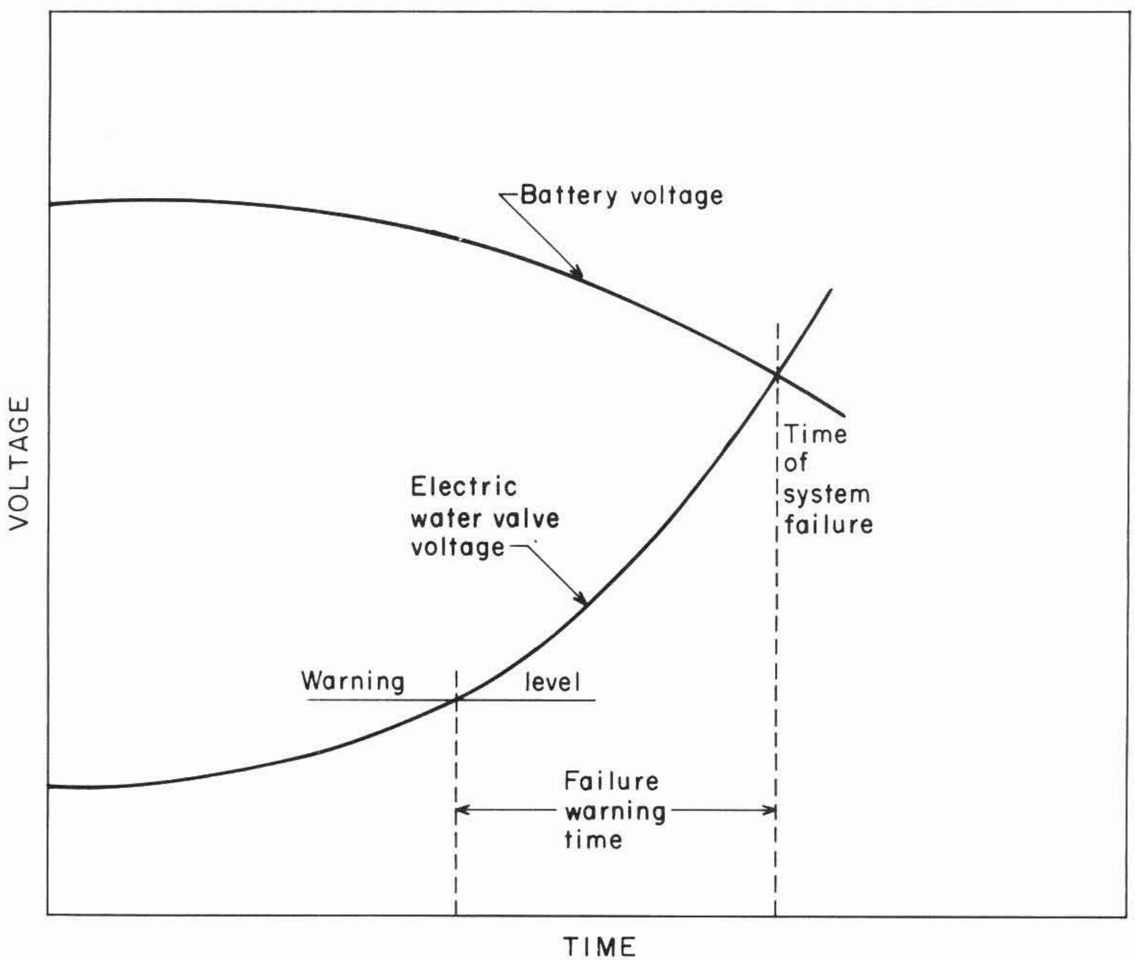

Figure 3.–Predictive diagnostics can prevent failures.

properly, it passes; if not, it fails. In the foregoing example, the water valve actuator may pass a single go-no go test even though it is dangerously close to being underpowered. If tested 5 min later, or the next day, or the next week, it might not function properly. Maintenance personnel, who depend on go-no go testing, could erroneously conclude that a system is functionally sound when in actuality, it requires immediate maintenance attention.

By measuring and recording functional parameters such as battery voltage and valve actuation voltage, maintenance personnel can more confidently predict and prevent future system failures. Even where considerable scatter exists in individual measurements, a trend will generally be evident over time. This maintenance technique is referred to as predictive diagnostics; predictive because it anticipates future performance, and diagnostic because the goal is to identify the cause of the performance decrement.

The other general type of system failure that can occur is random failure. Random failures are usually caused by discrete, unpredictable events. Causes of random failures would include mechanical damage due for example, to a roof fall, or the abrupt failure of a component due to a manufacturing defect. Both predictive diagnostic testing and go-no go testing can be used to identify random failures. However, because of the random nature of such failures, predictive diagnostic testing cannot predict future random failures.

Wear out failures can appear as random events if appropriate predictive diagnostic measurement and trending is not practiced. Thus, care must be taken to analyze fully all system failures to determine whether the failure was truly random, or if it was caused by a previously unnoticed environmental exposure effect. If the latter is true, the inspection procedure should be modified to monitor that condition in the future.

The CFR requirements listed in the previous section should be regarded as minimum standards. They are visual, and go-no go tests that are designed to identify device or system failures after they have occurred, so appropriate maintenance and repairs can begin to restore proper system operation. They are generally not designed to anticipate future system failures. Failures identified through such inspections could conceivably have existed since the conclusion of the previous inspection.

The CFR incorporates by reference, NFPA inspection and maintenance requirements for the various fire suppression system types. These requirements were prepared by NFPA for general industrial occupancies, and do not consider the unusually harsh environmental exposures, which are common in underground mining. They too must, therefore, be considered minimum requirements. Accordingly, although continuous system readiness cannot be guaranteed, supplementing the CFR requirements with predictive diagnostic testing and, if necessary, increased frequency of inspections, is strongly recommended.

CONVEYOR FIRE PROTECTION SYSTEM FAILURE MODES

NFPA 13A "Recommended Practice for the Inspection, Testing, and Maintenance of Sprinkler Systems" cites reasons for unsatisfactory automatic sprinkler performance in general commercial applications. Shutoff sprinklers caused 30 pct of all system malfunctions. Inadequate sprinkler coverage caused 26 pct of malfunctions. Inadequate water and line obstructions caused 13 pct, faulty building construction 13 pct, inadequate system 7 pct, inadequate maintenance 4 pct, and unknown causes account for 7 pct. From this list, 83 pct of automatic sprinkler system failures (all except faulty building construction and unknown causes) are the result of causes that could be identified and corrected through appropriate sprinkler system inspection and maintenance.

The underground mining environment also contributes to automatic sprinkler failures. Breakage of waterlines is often a result of low clearance, unstable roof, and system over pressures caused by mine depths. System freezing can occur at entrances in cold weather, and rock dust can cover sprinkler heads. Figure 4 shows a rock dust caked automatic sprinkler head. The actuation response of this sprinkler would be considerably slowed at best, and would be too late for effective extinguishment, or at worst to the point of not opening at all. Also, due to the fact that mines seldom even try to comply with sprinkler water quality requirements, scale buildup resulting in the plugging of sprinkler heads is a bigger problem in mining

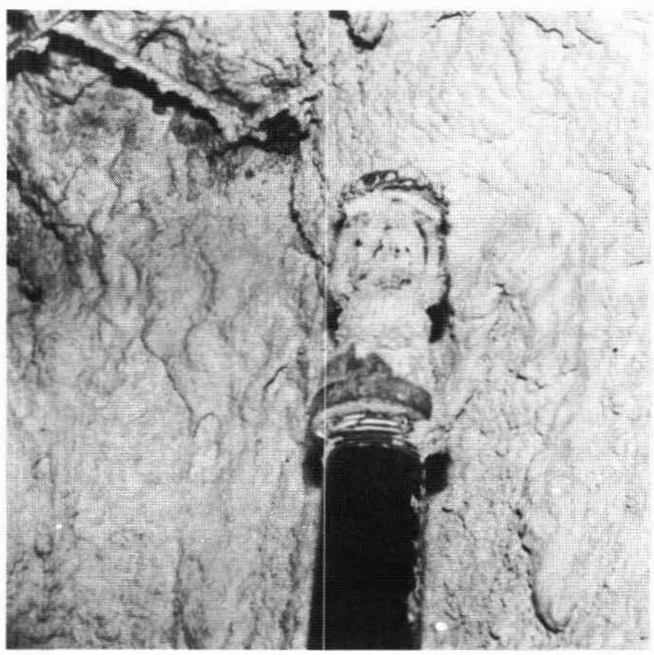

Figure 4.-Rock dust caked automatic sprinkler head.

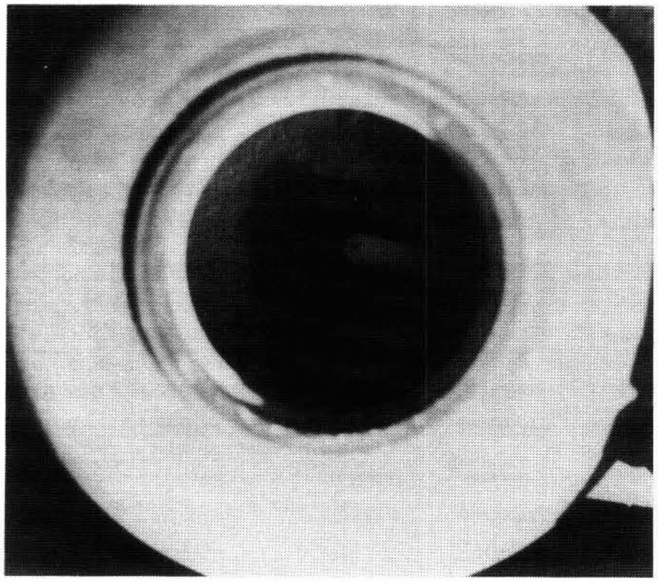

Figure 5.-Caked dry chemical agent due to moisture contamination.

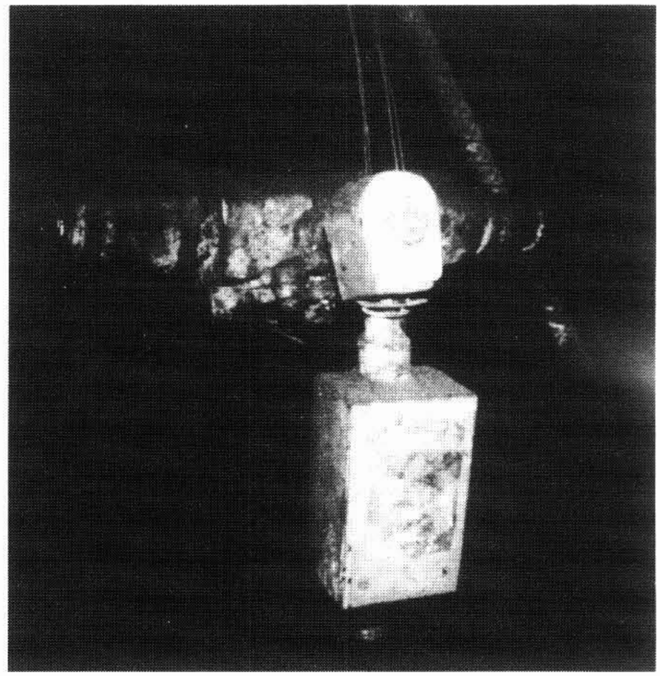

Figure 6.-Bent pilot water valve.

than for general industry. Some mines prefer water deluge systems to minimize this problem.

Failures of water deluge type systems, and high expansion foam systems would occur as a result of water supply related failures, since these systems also require available and sufficient quantities of water. Line clogging, improper coverage, and caking are potential failure modes for dry chemical distribution systems.[5] Figure 5 shows most of the chemical agent remaining in a dry chemical extinguisher because of moisture induced caking.

The electric control units and actuation valves are similar for water deluge, high expansion foam, and dry chemical systems. Table 2 lists common failure modes for these three system types. This table summarizes findings of MSHA electrical inspectors responsible for inspection of belt protection automatic fire suppression systems. Notice that batteries, contact points, control wires, and electric servos are all prone to failure. Figure 6 shows a mechanically damaged (bent) electric water valve. Although this water valve functioned properly, mechanical damage to any component will lessen its reliability, as well as obscuring any later significant damage. Figure 7 shows an unsecured sensor line, the connection to the heat sensor (below the upper left bracket) could easily be broken. Figure 8 shows a battery power test (with load) showing a near fail condition.

Thorough statistics are not available; anecdotal evidence strongly supports the conclusion that belt drive suppression systems suffer reliability problems. Limited field testing conducted as part of this research (*6*) revealed impending and intermittent failure conditions in three of the six electrically controlled systems tested. Figure 9 shows a water deluge electric control system being tested. Each of the belt drive fire suppression systems tested were functionally tested and maintained by mine personnel before each research test. The intermittent failures were caused by rock dust contamination of exposed relay contact points as shown in figure 10. The impending failure was the result of low battery power and a high dry chemical valve energy requirement.

[5]Allen Corp. of America contract H0292011.

Table 2.-MSHA survey of common fire suppression failure types

System type	*Failure modes*
Water deluge systems	Relays inoperative. Dead batteries. Clogged waterlines. Spray nozzles clogged. Moisture in control box. Battery corrosion. Sticky solenoid valve. Insufficient or no water supply. Heat sensor failure. Broken wiring. Burned out belt shutoff.
Dry chemical systems	Trigger device seizure. Moisture and corrosion in control box. Blocked or broken distribution hoses. Caked dry chemical.
High expansion foam systems	General problems with compressed gas powered systems.

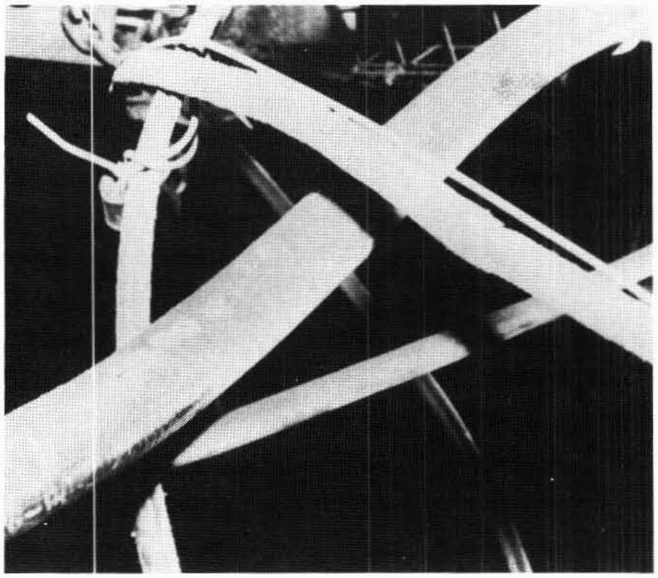

Figure 7.–Improperly hung heat sensor and cable.

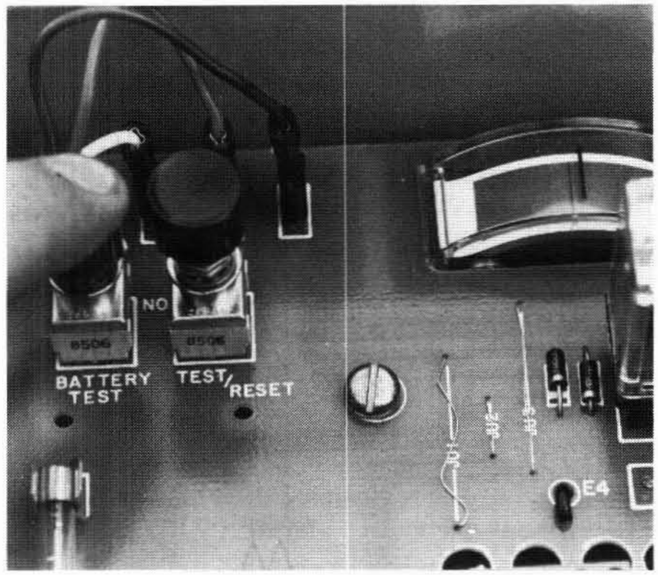

Figure 8.–Battery test.

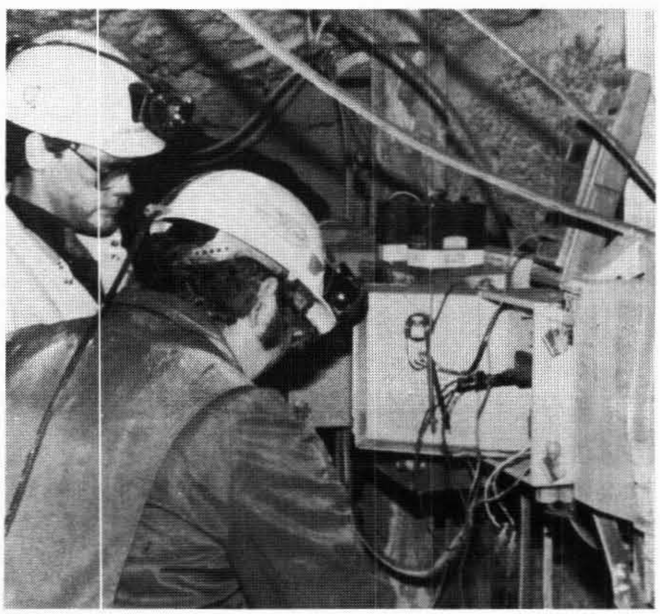

Figure 9.–Test of water deluge electric control box.

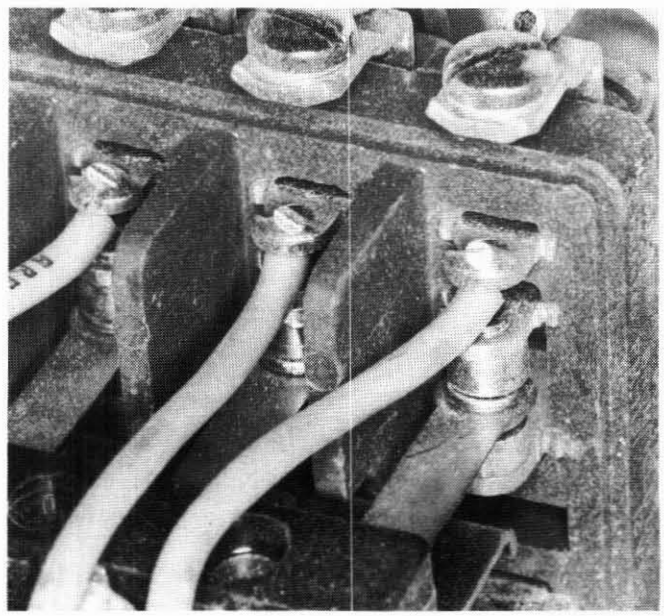

Figure 10.–Rock dust contaminated relay contact points.

AUTOMATIC FIRE SUPPRESSION SYSTEM INSPECTION CHECKLIST

These inspection recommendations are based on discussions with MSHA inspectors, a review of manufacturers' literature, discussions with mine personnel, field data, and in-house observations of automatic suppression systems. The following inspection procedures are suggested as guidelines to supplement manufacturer's recommendations and do not have precedence over CFR requirements. The procedures are presented according to functional groups. In each case, increasing the number of individual measurements increases the confidence level of the results obtained.

DETECTOR AND CONTROL

Detector and control systems are similar for water deluge, dry chemical, and high expansion foam systems. Detectors most typically consist of point bimetallic type sensors. Two conductor wires with melting insulation, fusible links, or optical flame detectors are also used. Common system actuators are electrically controlled water valves, and electrically controlled dry chemical seal rupturing devices.

Inspection for electrically controlled systems includes checking for wire continuity (absence of breaks) as well as sensor function. Continuity can be checked at the control box end by shorting the far end sensor, or with sensor loop test circuitry. Wires should be securely strung without being loose or tight, and wire connections should be made using appropriate methods. Clear wire labels or coding are recommended. Check cable clearance around moving machinery, and interference with access ways. Check for moisture and rock dust around connectors, which can lead to corrosion and discontinuity.

Heat Detectors

Resettable point type heat detector function can be checked on a sampling basis by heating the sensor in place, or by a schedule of replacement and lab testing. Sensor resistance should be infinite when open, and close to zero (0.1 ohms or less) when closed. Unusual readings indicate possible contamination or corrosion. Figure 11 shows a cut-away view of a typical point type heat detector showing the normally open contact points, and a bimetallic disk heat detecting element. When the bimetallic disk element is heated, the convex disk pops to a concave position allowing the points to close. To function properly, the disk (on the bottom of the sensor) should aim towards the area to be protected. Closure temperature should correspond to values printed on the sensor. Sensors with outlying closure temperatures, or any signs of mechanical damage should be replaced.

Continuity of fusible link systems and shorting wire systems should be checked. Optical heat detectors must be kept clean, and they should be functionally tested with a test light. These types of detectors are not common in underground mining, and close adherence to detector manufacturer inspection and maintenance procedures is recommended.

Electric Control Boxes

The electric control box functions include turning on the suppression device, shutting down the belt drive, and providing a fire warning. Figure 12 shows a simplified functional diagram of control box function. Sensor continuity, suppression system actuation, and belt drive shutoff can all be verified from the control box. Some systems have built in testing circuits for sensor wire continuity and battery condition. Before attempting a functional test on dry chemical systems, remove the actuation head. Functional

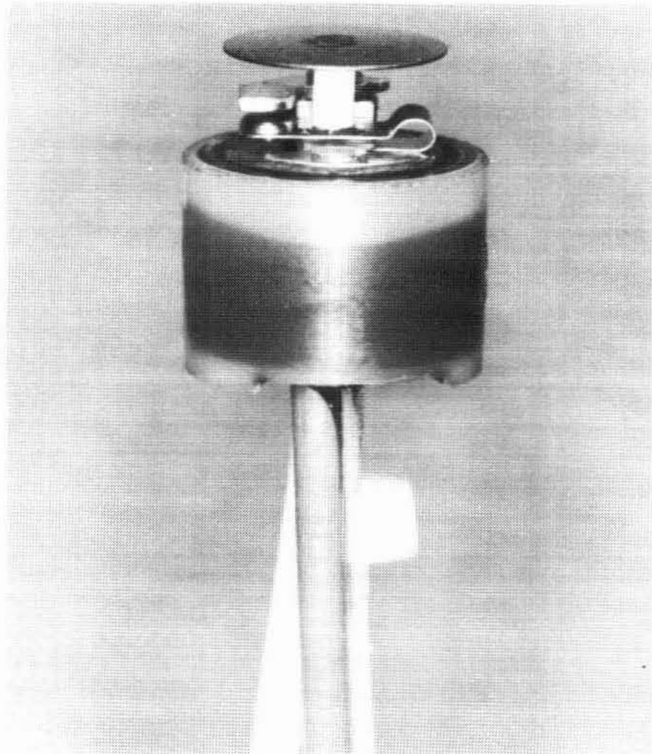

Figure 11.–Cutaway showing point type heat detector components.

tests typically are performed by shorting the sensor leads. These tests should be performed according to the manufacturer's recommendations.

Typical control box functional tests are go-no go in nature with no margin of safety. Because systems could fail immediately after passing a functional test (intermittent failure condition) or a short time later (impending failure condition), a simple test modification is recommended to add a margin of safety. This modification involves temporarily placing a power resistor in series with the battery during functional tests (fig. 13). This resistor simulates the increased internal resistance that occurs as batteries age. This test method verifies the condition of the battery and all power dependent components in the circuit including the first stage of the electromechanical actuator valve,[6] wiring, connections, and relay contact points. This test method can be thought of as moving the curves of figure 3 closer together to screen failures. The size of this resistor depends on the control circuit type. A one-half power test would require an added resistance to drop 29 pct of the no load battery voltage. ($P = V^2/R$, where P = power, W; V = voltage, V; and R = resistance, ohms) or alternatively reduce current by 29 pct ($P = I^2R$, where I = current, A). For example, a 12 V battery system drawing

[6]The margin of safety does not apply to later mechanical stages such as the main springs of mechanical latch valves, or diaphragms of pilot relief type valves. These must be assessed independently.

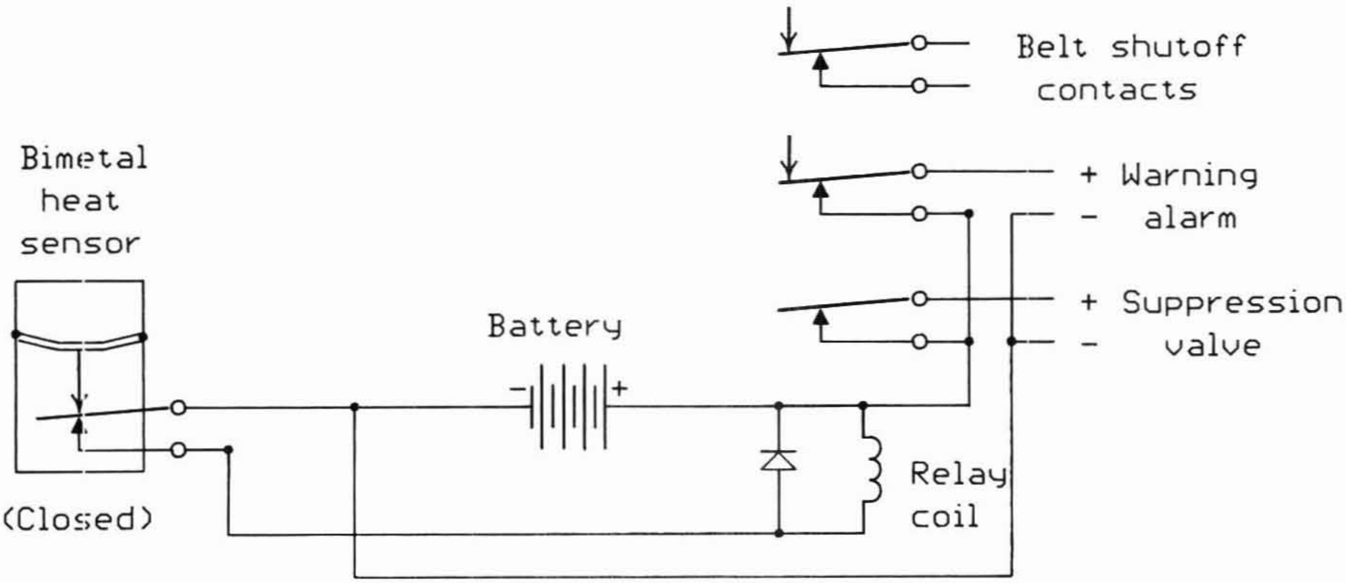

Figure 12.-Simplified fire suppression electric control functions.

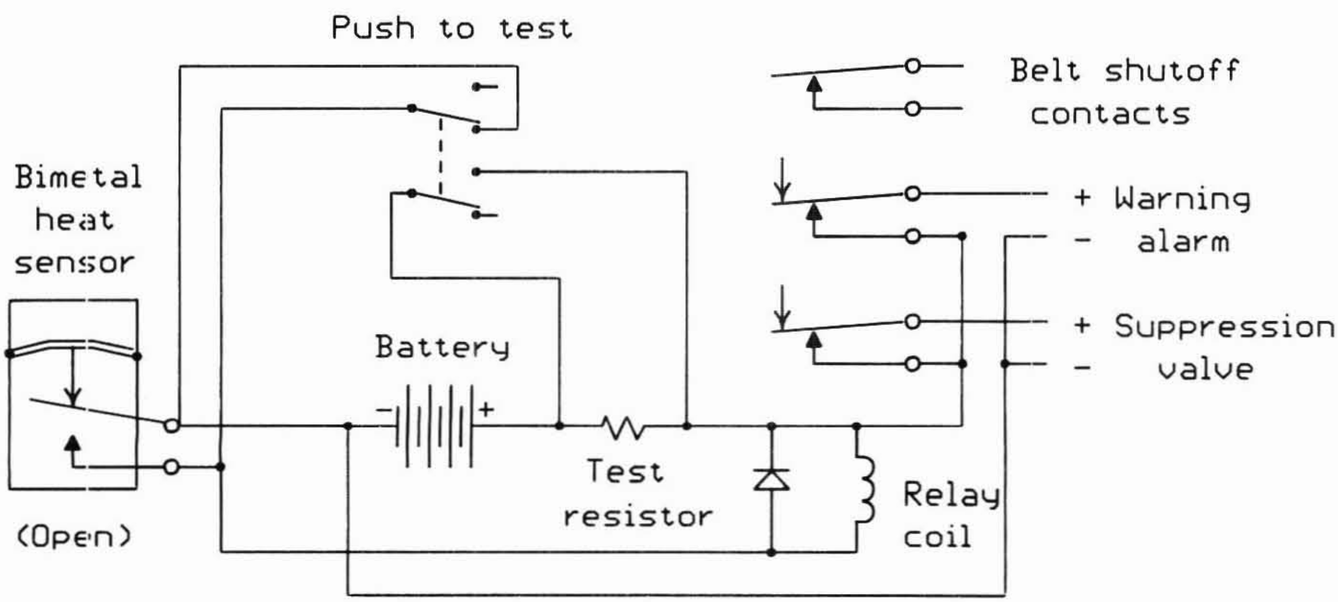

Figure 13.-Modification of functional test to add margin of safety.

1 A when functioning would require 3.5 ohm resistor in series (29 pct × 12 V = 3.48 V). Remove this resistor for normal system operation. The parallel load resistor in some systems with built in battery test circuits may also be used for a low power test. To do this, press the battery load test button during the functional test. Do not hold this load test button down too long because it drains the batteries. System manufacturer's should be consulted before attempting any test modification.

Electric control boxes should be dust and water tight. Look for secure mounting with secured cable runs. Figure 14 shows improperly mounted control boxes with unsecured control wires. The wires illustrated in this figure could break or be pulled from connectors. Control and actuator wires should pass through water tight bulkhead fittings. These fittings should be on the bottom of the box. If testing requires that the control box be opened, clean the outside of the box to prevent contamination by

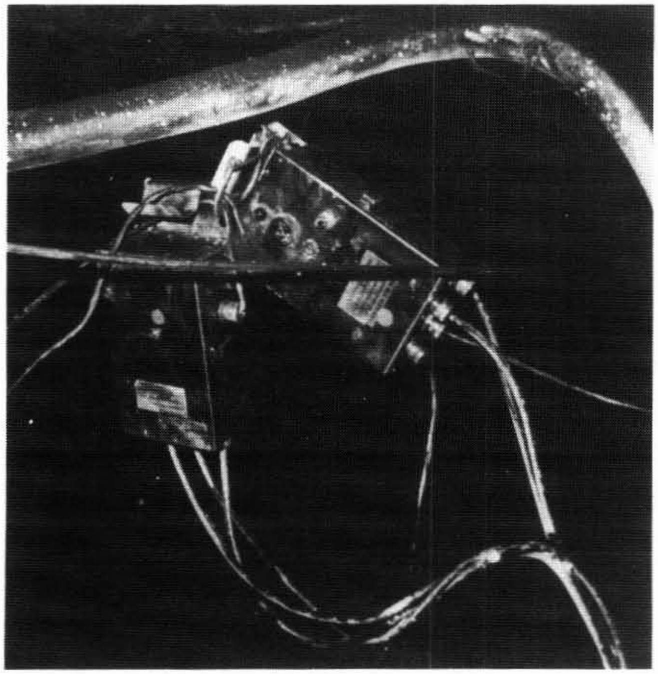

Figure 14.–Improperly secured control box and wires.

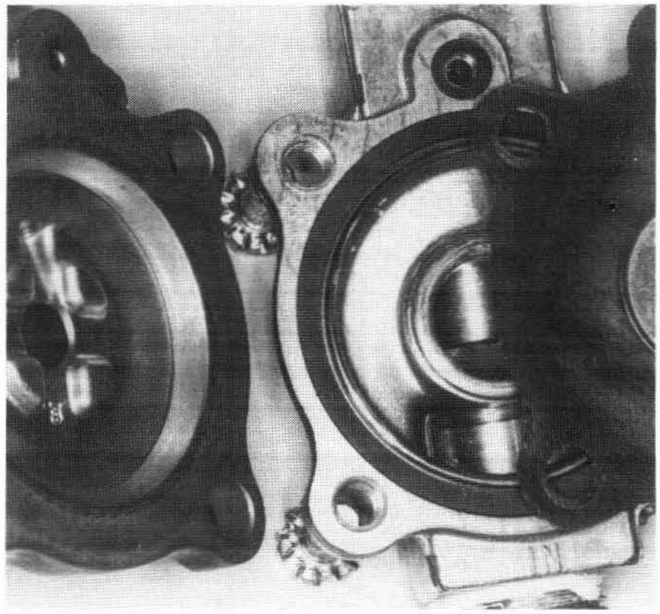

Figure 15.–Diaphragm, seat, and bleeder holes of pilot valve.

rock dust or moisture. If water, dust, or corrosion is present inside the box, repair the seals or replace the control box. Carbon zinc or alkaline batteries should be replaced on a quarterly basis. Battery internal resistance should be checked weekly on systems that are not line powered.

Actuator Valves

Automatic valves should be kept clean. Pilot diaphragm relief type valves should be inspected regularly. To open properly, the small pilot bleeder path must be kept clean, and the rubber diaphragm must not be damaged. Figure 15 shows the bleeder path and the diaphragm. The pilot hole in the top causes a pressure difference across the diaphragm that allows it to open. The small hole in the diaphragm allows the valve to close. If clogging or tearing is persistent, pilot valves should be replaced by direct opening type valves. Latch mechanisms for latch type one-fourth turn ball valves must be kept clean. Valve stems should rotate freely. All moving parts should be corrosion resistant and covered. Mechanical latches on dry chemical systems should be kept free. Pressure ratings of valves should not be exceeded. Valves can be damaged by excessive pressure and water hammer (the concussion of moving water in a pipe). Pressure regulators and relief valves should be installed as necessary.

Pneumatic Systems

Pneumatic detector and control systems are not as common in the mining industry and will not be described in detail. If properly designed and installed, these can be reliable systems that function in a fail-safe manner (detector failures cause system actuation). Pneumatic systems typically consist of melting sensor tubes or sensors, which release pressurized fluid that turns on a valve through a diaphragm, piston, or pneumatic motor. System leaks and mechanical seizure will be the primary causes of system failure. Since mechanical systems are analogous to electrically controlled systems, the general maintenance concepts presented above apply.

SUPPRESSANT DISTRIBUTION SYSTEM

Automatic Sprinklers

Make sure sprinklers are not caked with rock dust. Rock dust acts as a thermal insulator and will delay actuation times or prevent the sprinkler from opening. Make sure risers are clear of suspension chains or other objects, as movement of waterlines due to flow changes could break risers. Figure 16 shows a sprinkler riser too close to a suspension chain. Make sure waterlines are secure. Verify water pressure by opening a bleeder valve. Waterflow equivalent to one nozzle should trigger the belt

Figure 16.-Suspension chain too close to riser.

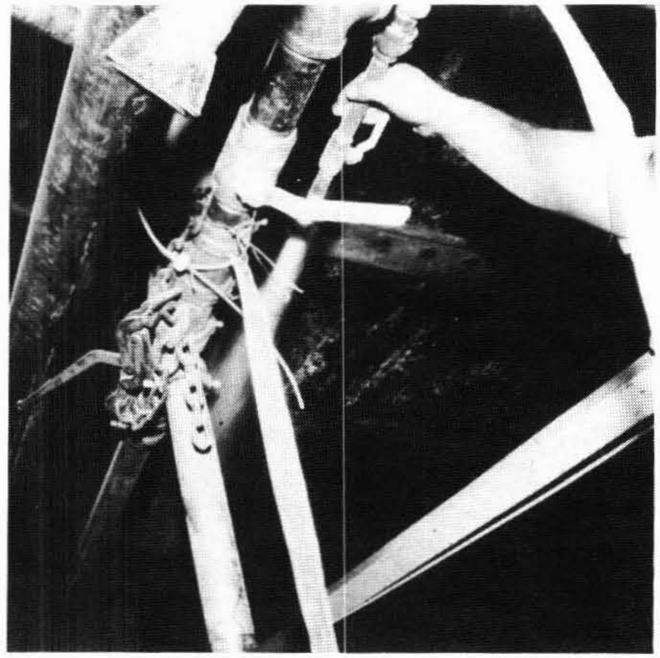

Figure 17.-Discharge test of automatic sprinkler system.

shutoff switch and provide a warning. Figure 17 shows a functional test of an automatic sprinkler system with the opening of a bleeder valve. Notice the valve identification flag. This clear identification makes inspection easier, and reduces the chances of accidental valve closing. Inspect electric shutoff cables with the same guidelines as other sensing and control wires. Verify water supplies back to the source checking pumps, waterlines, pressure regulators and valves. Water pressure, flow rates, and line contamination should be addressed in the inspection plan. As noted previously, more sprinkler system failures are due to the water supply being shutoff than from any other cause (30 pct). System flushing should be done in a manner prescribed by the NFPA 13A. Damon (*13*) suggests a sprinkler system inspection procedure with intervals ranging from daily to annually, with written inspection records.

Water Deluge Systems

The most common failure of water deluge distribution systems is rock dust clogged nozzles due to the removal of nozzle caps. If nozzle caps are not in place, systems should be flushed by opening the end of the hoseline to full diameter and flushing with water. After flushing, nozzle caps should be put back on all nozzles. Check for secure waterlines with clearance from moving rollers and belt. Nozzles should be directed to both sides of the top belt, and the top side of the bottom belt. The maximum nozzle spacing is 8 ft for the first 50 ft of fire resistant belt or for 150 ft of nonfire resistant belt. A functional test is recommended annually. During this functional test, make sure all nozzles are flowing full. If any nozzles are not flowing full, clean those nozzles and screens, and flush the nozzle lines. Check the strainer after each test.

High Expansion Foam Systems

Foam systems should be thoroughly inspected and checked by qualified personnel. Regular service contracts with the manufacturer or installing company is recommended (NFPA 11A-10). Foam suppression systems must be of proper size and located to take advantage of ventilation currents. Foam systems must be near the roof to prevent foam from being drawn into the intake, which severely reduces effectiveness. Figure 18 shows a typical foam generator being functionally tested above a conveyor belt. Foam systems cannot be used where they would draw smoke-contaminated air into the blower.

Compare the capacity of the generator with the area to be protected. The CFR requirement is that 50 ft of fire resistant belt be covered in 5 min. Under ideal conditions this would require a minimum capacity of 10 ft^3/min for each square foot of coverage cross section. For example, a 8-ft-high top belt by 20-ft-wide drift would require a 1,600-ft^3/min foam generator (50 ft coverage). Multiply this capacity by 3 for non-fire resistant belt (150 ft coverage). Bulkheads should be installed to allow the foam to cover the belt adequately. A 5-min test is recommended to verify adequacy of coverage.

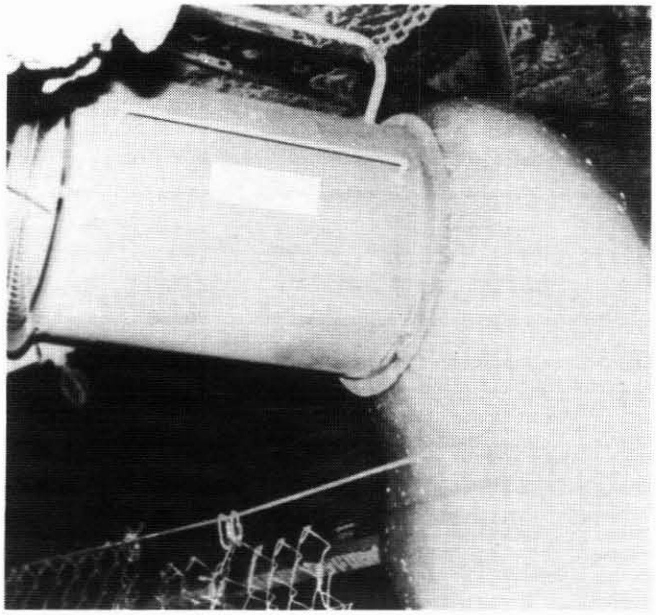

Figure 18.–Functional test of high expansion foam system.

The generating fan in current model foam generators is powered by a water turbine. When inspecting these water turbine systems, look for possible binding caused by rock dust or corrosion and verify that turbine blades turn freely. Observe that foam spray nozzles are not clogged (water only test). Diesel, electric, and pneumatic motor driven systems are not as reliable as water driven systems (for unattended operation) and are not recommended for use as fixed automatic fire suppression systems.

Verify that water pipe sizes and pressures are consistent with manufacturer's recommendations. These recommendations should be on identification plate. Typical pressures needed are 90 psi during operation. Excessive pressures at the eductor will compromise eductor effectiveness, while inadequate pressures will not allow sufficient foam to be generated.

Check eductor setting for foam concentration. Typical foam concentrate settings range from 1 to 5 pct, and vary according to the type of foam used. The concentrate setting should be printed on the foam container.

Check foam container for sludge or sediment on the bottom. Be sure container is vented, but without openings that would allow rock dust to contaminate the foam concentrate. Make sure the foam container is located upair from the generator, or in the intake airway.

Foam concentrate properties such as viscosity and frothability should be checked by qualified personnel. Properties may change due to freezing.

Annual functional testing is recommended, and can be performed with the foam eductor in either foam or water. Measure the eductor flow, a 1-pct eductor setting with a 50-gal/min foam generator should consume 0.5 gal/min. Significantly higher or lower eductor draw indicates possible malfunction or clogging. The foam will settle naturally in about an hour, application of water mist or rock dust will cause the foam to settle immediately. Replace foam concentrate after tests with the same type used. Water can be used alone for functional testing. Clean the water motor and eductor by flushing the eductor in a bucket of clean water after each test (or optional lubricating additive supplied by the manufacturer). Check and clean strainers after use.

Dry Powder Chemical Systems

The weekly visual observation shall verify that manual actuators are not obstructed, that tamper indicators and seals are in place, that no obvious physical damage or condition exists which may prevent operation, and that pressure gages are in operable range (NFPA 17-110). This check shall also verify the presence of nozzle covers, intact control wires, and distribution lines.

NFPA 17 requires that dry chemical systems be maintained at least semiannually in accordance with the manufacturer's maintenance manual. This maintenance shall include examination of detectors, compressed gas containers, actuators, hose, nozzles, alarms, and auxiliary equipment. Dry chemical powder shall be examined semiannually for caking with the exception of stored pressure types, which should be examined every 6 years. Weigh and check pressures of gas cylinders and containers as appropriate. Examine chemical containers for corrosion or pitting, and if evident, repair and test according to manufacturer's recommendations.

Make sure dry chemical systems are securely fastened and protected from possible impacts, sources of corrosion, and contamination. Actuators shall be in the armed position. Actuators shall be removed from systems before routine functional testing is performed. Figure 19 shows removal of a dry chemical system actuator head. After testing the firing plunger, reset the plunger into the depressed position before replacing the control head.

Nozzle caps should be kept on nozzles to prevent clogging with rock dust. Purge distribution lines with compressed air after each chemical discharge, or if nozzle caps are missing. Replace nozzle caps after purging. Check to see that the path from the nozzles to the belt surfaces is not obscured. Previous research has shown that dry chemical fire suppression systems for conveyor belt fires are minimally effective with little safety margin due to flame reignition (Allen Corp. of America contract H0292011). Reignition could occur if the suppressant agent does not totally and uniformly cover the involved fire area. Because agent discharge occurs over a short period, it is important that the conveyor shutdown quickly. It is also important that detectors have a fast response so fires do not have a chance to become deep seated.

Components, including hoses, valves, manifolds shall be pressure tested by an approved laboratory every 12 years. Chemical agent shall be discarded, and system shall be carefully checked, reassembled, and recharged. Mine protection shall be maintained during this laboratory testing.

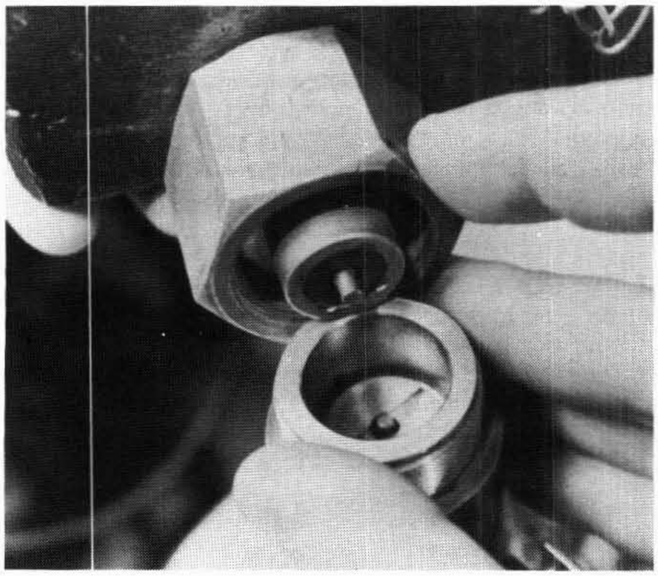

Figure 19.–Removal of dry chemical actuator head.

BACKUP WATER SYSTEM

Automatic fire suppression systems are designed to control and prevent the spread of fires, but will not guarantee total extinguishment. System failures or fires outside the area of coverage may also be reasons fires are not extinguished. This is why a backup water system is important. Even if fires are successfully extinguished by an automatic system, further cooling and observation with a ready firehose is essential. In underground coal mines, this backup hose connection together with a sufficient length of hose shall be located within 300 ft of the belt drive (30 CFR 75.1101-9), with outlets every 300 ft along the beltway (30 CFR 75.1100-2b). This outlet and hose location shall be clearly identified in the mine's fire fighting plan. Identification of the hose and necessary connections should be part of the weekly inspection. All hoselines and connections should be checked to ensure that sizes are correct. Observe maximum pressure ratings of firehose. Over pressure is one common problem contributing to hose rupturing.

DESIGN INCORPORATIONS TO IMPROVE RELIABILITY

Several advanced features are recommended for incorporation into automatic fires suppression systems to improve their reliability. These are reliable components and construction, built-in diagnostics (with margin of safety) (*6*), and ease of inspection. These features should be designed as an integral part of all automatic fire suppression systems to facilitate a reliable inspection and maintenance program. Building in system reliability is one important method of preventing system failures. This is achieved by good design, quality manufacturing techniques, and proper installation. Even so, because of the complexity of automatic fire suppression system function and the adverse chemicals, temperature, and moisture conditions encountered in the mine environment, failures will occur over time. The dynamic nature of mining with advance workings, moving machines, and abrasive and corrosive materials will add to the possibility of early failures. This is why built-in diagnostics and ease of inspection are critically important.

RELIABILITY THEORY

System reliability is measured as the mean time between failures (MTBF).[7] The fraction of system downtime due to deficiencies will be equal to the inspection interval divided by the MTBF times 0.5 (assuming the inspection is totally reliable, and that repair is immediate). If the MTBF is 5 years and the inspection interval is 1 year the probability of the system failing (during a fire) is 10 pct. Predictive diagnostics and robust design can increase the MTBF. Frequent inspections, when accurate, will also reduce the probability of failures.

System deficiencies should be identified and corrected as soon as possible. Deficiency conditions related to wear out can be averted by predictive diagnostics. Predictive diagnostics measurement methods should be incorporated into fire suppression systems. Random deficiency conditions can be identified by fail safe design (failures activate the suppression system), and by inspection and testing. System design should include provisions for ease and confidence in inspection. Because some conditions such as line power loss or electrical discontinuity cannot be visually inspected easily, trouble flag indicators are suggested. Inspections for these types of failures should be done on a daily or weekly basis and should allow condition assessment at a glance. Boyd (*14*) suggests built-in-test (BIT) equipment to monitor important system parameters such as water pressure or pump starting characteristics. This BIT equipment could be made part of a mine-wide monitoring system.

HARDWARE DESIGN RECOMMENDATIONS

The following general design recommendations are based on a study of failure modes and observations of systems in operating mines.

Electronic Control Unit

1. The control unit enclosure should be an environmentally sealed National Electrical Manufacturers

[7] Because the objective is to prevent failures (fire suppression system not working during a fire) MTBF should be thought of as mean time between deficiencies. Failures can then be prevented by correcting deficiencies.

Association (NEMA) type 4 enclosure. All wiring should pass through water and dust tight bulkhead fittings. The enclosure should be equipped with a thermostatically protected small wattage heater to prevent water condensation on system components. Flexible silicone heaters are recommended since they are inexpensive and very reliable.

2. System controllers should be powered by a 110 V ac supply with battery backup to provide power in the event of a line failure. (NFPA 72C "Remote Station Protective Signaling Systems" requires two sources of electric power, a primary and a secondary. Primary batteries (dry cell) are not permitted.) Battery-only powered systems require frequent battery tests. If battery-only systems are used, the battery tests should measure battery power under simulated load conditions. Electric power malfunctions should be indicated by mechanically latched trouble flags. Two flags are recommended, one for line power failure and one for low battery voltage. These flags should be inspected on a daily basis. A set of trouble indicating relay contacts should be provided for connection to a mine-wide monitoring system.

3. Printed circuit boards should be conformally coated or hermetically sealed to prevent moisture, corrosion, or contamination problems.

4. Solid-state components should be soldered directly to the printed circuit board without the use of sockets.

5. Electromechanical components such as relays and switches should be hermetically sealed to prevent contamination of the contacts. Relay contact points should be used in the normally closed position if possible. Solid-state switches with optical isolation (as necessary) are recommended for increased reliability.

6. Military type, high temperature, ceramic packages should be used for all semiconductor devices. Power devices that dissipate heat should be properly heat sunk to prevent thermal damage.

7. Systems should incorporate low voltage test circuits to measure battery power, relay resistance, sensor line continuity, and control valve actuation power. These test circuit connection points and switches should be enclosed in a separate box or partition from the main power circuit. Trouble latches, and important measurement parameters should be connected to mine monitoring systems. Figure 20 is a block diagram of this design concept.

8. Mine monitoring systems can be used to activate fire suppression systems using an independent valve and power supply.

9. Fire warnings should occur at manned locations.

Suppressant Distribution System

1. Water deluge sprinkler head and dry chemical nozzle openings should be covered with protective caps to prevent clogging due to rock dust. These caps should be tethered to the sprinkler body to prevent loss during testing. Spring loaded self-seating orifice balls or needles could also be used.

2. Automatic sprinkler heads should be covered with a wax coating to minimize the effects of rock dust caking. These should be washed if coated with rock dust.

3. Direct acting mechanical valves should be used. Control valves should be matched for the control voltages, fluid pressures, and extinguishment flow rates. All moving parts should be housed and protected from rock dust. Actuation voltages of automatic valves should be less than 75 pct of the applied voltage.

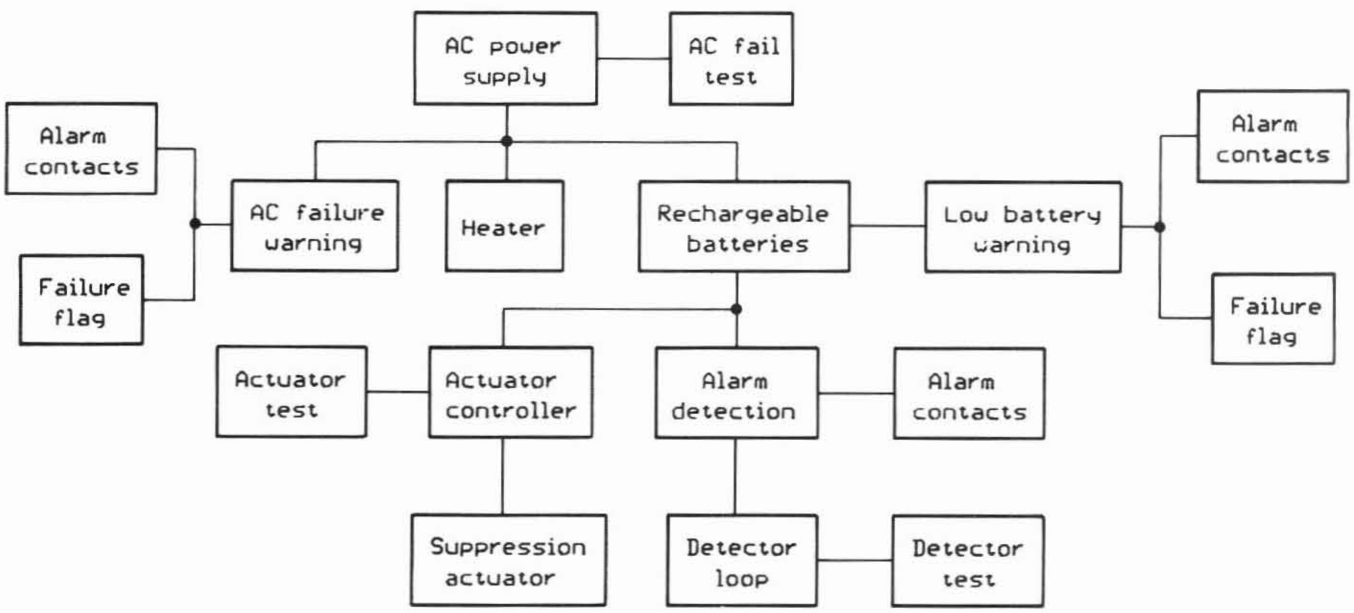

Figure 20.–Block diagram of normally closed detector electric control unit.

4. Manual bypass valves to turn on the suppression system independently should be clearly identified in an accessible location, away from the conveyor system.

5. Pressure gauges should be installed on water supplies downstream from the strainer. An excessive pressure drop during testing would indicate valve or strainer constriction. Figure 21 shows a pressure gage installed on the discharge side of the strainer to indicate line pressure and pressure drops.

6. Foam systems should be properly located, and sized for the area to be protected. Bulkheads should be located to allow sufficient foam coverage.

7. Pre-engineered dry chemical distribution lines and nozzles should be sized for the belt to be protected. Mounting brackets should be used to accurately control the direction of dry chemical application. Obstructions such as decking or shields may necessitate a custom design.

Heat Sensors

1. Point type heat sensors should be hermetically sealed. Actuation temperatures and lot identification numbers should be printed on the sensors.

2. Normally closed sensors such as melting wires or links can be inherently reliable, if the return wire path is separate from the source wire (to prevent the possibility of shorting). Normally closed sensors require a constant trickle flow of current to detect an open circuit in the system and add some complexity to the circuit. Low power (CMOS) logic circuitry make normally closed detectors possible even with battery power.

These hardware recommendations are general and should be considered in the context of the entire design. Reliability cannot be added as an afterthought into the system. Simple designs are most reliable designs since the total system reliability is the product of the reliability of the individual components.

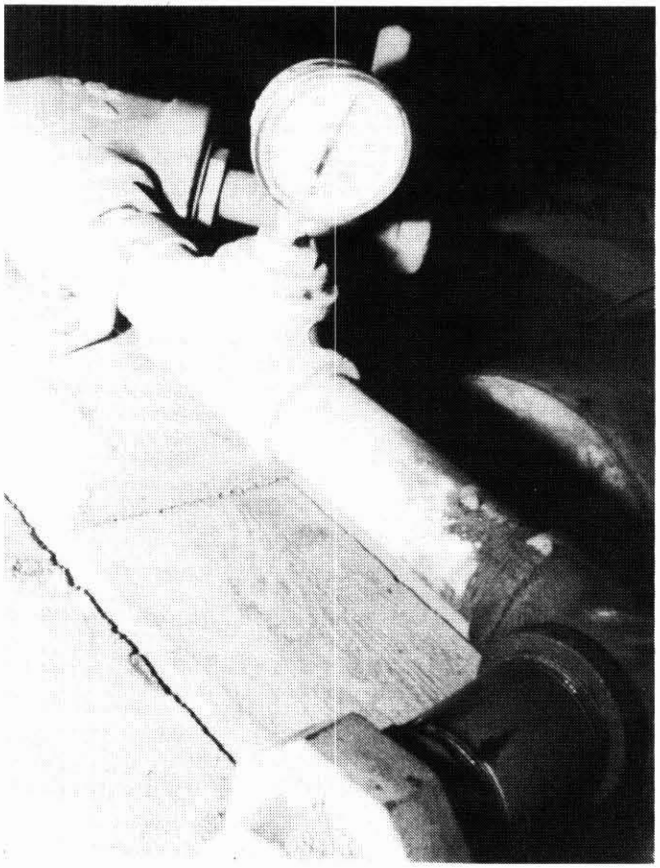

Figure 21.–Pressure gauge downstream from strainer.

CONCLUSIONS

The reportable fire incidence rate on conveyors in underground mining is high considering the numerous mandated fire control and suppression requirements. Automatic fire suppression system failures contribute to this incidence rate. Proper maintenance, testing, and design can improve fire suppression system reliability.

The minimum fire protection and maintenance requirements for automatic fire suppression systems on conveyor belt drive systems for underground metal-nonmetal and coal mines are listed in 30 CFR 57 and 75, respectively. Compliance with these requirements includes keeping written inspection procedures and records, which should follow manufacturer's recommendations as a minimum.

Numerous failure modes exist for components of automatic fire suppression systems. Electronic systems commonly fail because of circuit discontinuity due to corrosion or rock dust, discharged batteries, or to mechanical seizure of actuation valves. Failures of water supply pumps, regulators, and valves also occur. Failures can be classified as wear out related or random. Wear out failures can be anticipated and prevented using predictive diagnostics. Random failures occur all at once with no warning. Functional testing can determine the presence of a random failure, but only after some downtime. The effects of random failures can be reduced by reliable systems and frequent inspections. Systems should be designed so that visual system inspection can readily identify failures. Random failure modes that cannot be easily identified should be avoided in system design.

Proper corrective action for failures should include correction of the inspection procedures and/or hardware that allowed the failure to occur. The corrective action program should be systematically applied to all related system components, and should not be limited to replacement of the specific defect. For example, if an open point relay is found defective - all open point relays should be examined for a similar condition and replaced as necessary. The written inspection records should list corrective action as well as repairs.

Automatic fire suppression systems should be designed with the objectives of reliability and ease of inspection. Functional parameters that correlate with system wear out should be measured as part of a predictive maintenance program to prevent failures. The potential effects of random failures can be reduced by fail safe design, and trouble indicator flags. A weekly system test coupled with diagnosis circuitry should reduce system downtime to an absolute minimum. A backup plan should also be part of a mine's fire control strategy. Systems can fail in the underground mining environment. Prevention of failures can be best achieved by integrating frequent inspection and maintenance checks with reliable hardware design.

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