



AUTOMATIC FIRE SENSING
AND SUPPRESSION SYSTEMS
FOR MOBILE MINING EQUIPMENT

FINAL REPORT

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BUREAU OF MINES

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Final Report

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Automatic Fire Sensing and Suppression Systems
for Mobile Mining Equipment

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FOREWORD

This report was prepared by FMC Corporation, Engineered Systems Division, Santa Clara, California, under Bureau of Mines Contract HO262052. The contract was initiated under the Federal Coal Mine Health and Safety Research Program. It was initially administered under the technical direction of Twin Cities Mining Research Center with Mr. Guy A. Johnson as the Technical Project Officer. Mr. Johnson was succeeded by Mr. Kenneth L. Bickel in September 1976. Mr. Ron Simonich was the Contract Administrator for the Bureau of Mines.

This report is a summary of the work completed as part of this contract during the period June 1976 to January 1978. The report was submitted by the authors 27 January 1978.

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Sincere thanks are extended to all personnel of mine companies who participated in the contract by volunteering their vehicles, labor, and assistance during the in-mine testing and demonstrations. Mr. Jerry Ross, Mine Superintendent, and Mr. Larry Largent, Safety Coordinator of the Jim Bridger Mine; and Mr. G. D. Petrick, Manager, Mr. R. Sieferman, Mine Manager, and Mr. Carrol Lopez, Foreman, of the Diamond Crystal Mine are especially thanked for their active participation and cooperation during the 11-month test effort.

EXECUTIVE SUMMARY

This report describes a 19-month program, under Bureau of Mines Contract HO262052, to design improve, fabricate, install, and in-mine test five types of automatic fire protection systems. One basic system was previously developed for use on mobile mining equipment under two other previous contracts.

BACKGROUND

Under Contract HO122053, FMC Corporation studied the severity and causes of fires on mobile mining equipment. On large vehicles in which the escape ladders pass near the engine area, significant operator hazards were identified. Such fires also resulted in loss of costly equipment and loss of production. At the conclusion of the study, a prototype automatic fire protection system was developed, installed, and in-mine tested for a short time on an ore haulage truck.

Contract HO232059 provided for modification and validation testing of the system. Two versions of the fire protection equipment were installed on vehicles operating in open-pit mines. A series of planned fires and one accidental fire were successfully extinguished.

The automatic system developed incorporates features not previously considered for use on commercial mobile equipment although used for military applications. Such features include multiple fire and flame sensors, automatic test features, fail-safe logic, and thermal compensation.

In the early 1970s, many mine operators installed manually actuated fire protection systems, due to more stringent regulations and because the cost of a basic system was low. In fire situations, however, operators often panicked and either did not actuate the systems or actuated them only after the fire had destroyed much of a vehicle. Mine managers who experienced large fire losses promoted further development of the automatic fire protection system into a variety of systems which would be applicable to other types of mining equipment.

PHASE I, DESIGN, FABRICATION, AND FACTORY TEST

Phase I work began with visits to five mines and selection of two mines of differing environments to participate in the program: Diamond Crystal salt mine in Louisiana and Jim Bridger coal mine in Wyoming.

Five fire protection systems (Figure A) were identified and factory tested:

- System I, the existing FMC/Bureau of Mines system, including thermal and optical detectors, stored-pressure dry-chemical cylinders, logic control, and ambient temperature compensation.

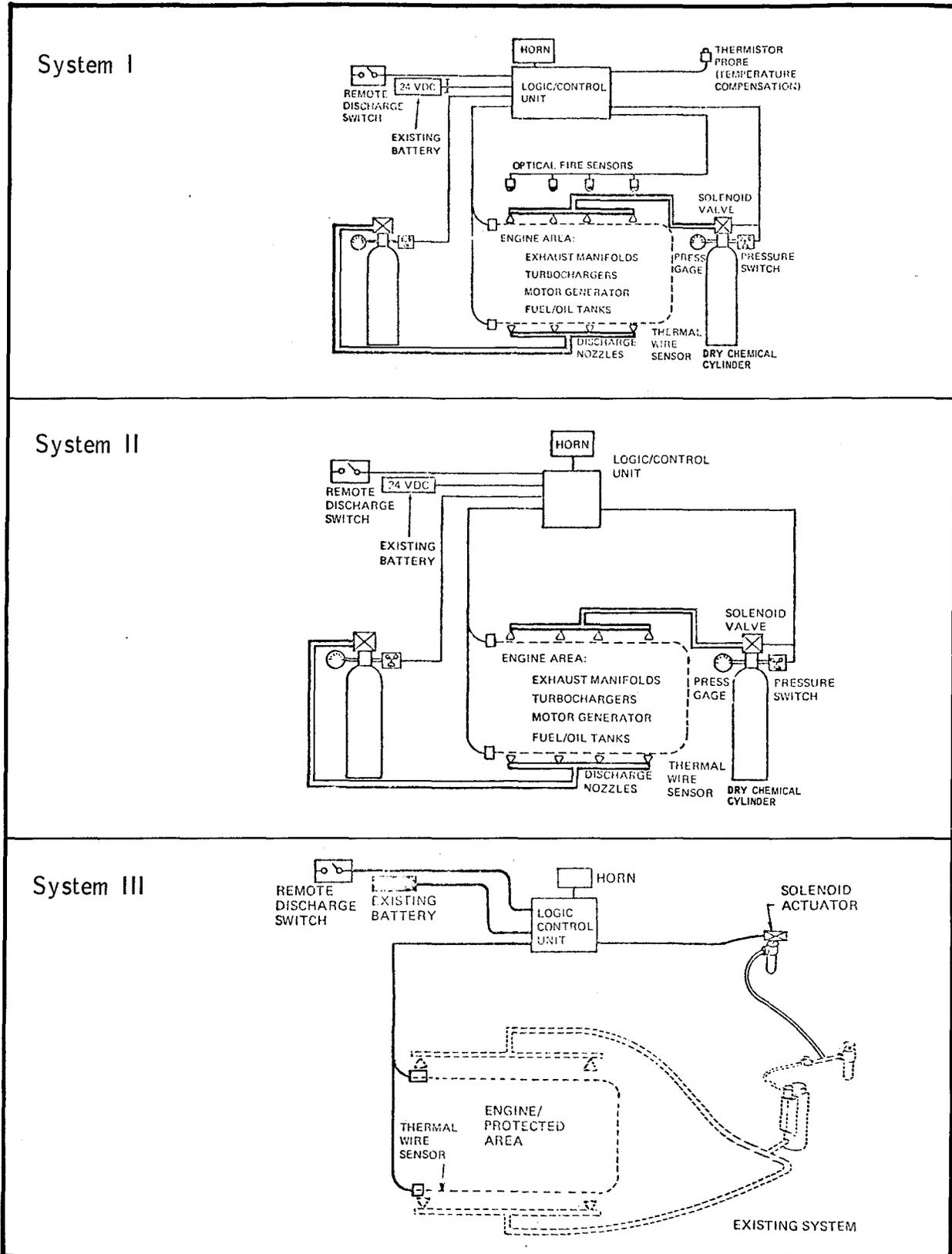
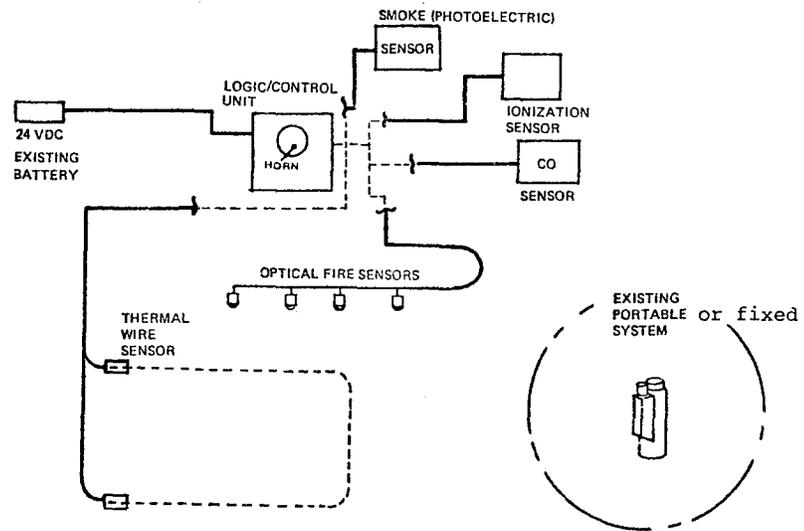


Figure A SCHEMATICS OF FIRE PROTECTION SYSTEMS (Sheet 1 of 2)

System IV



System V

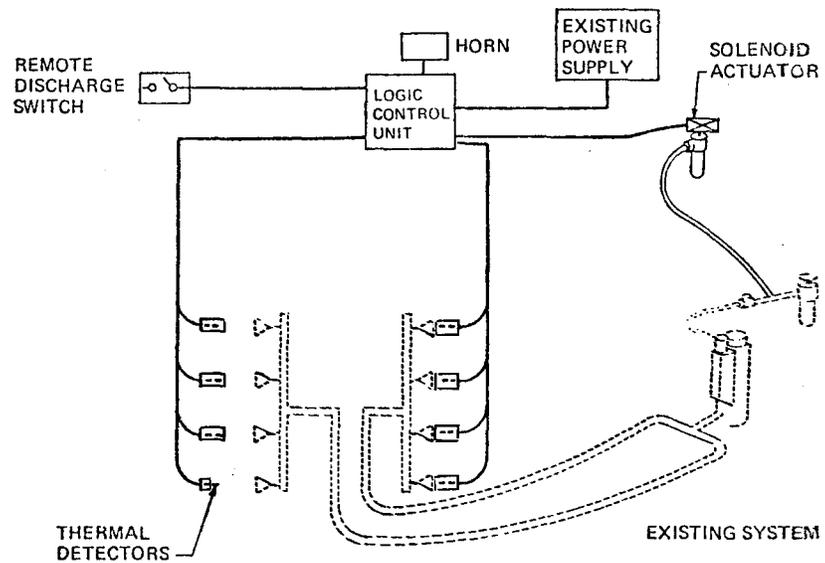


Figure A SCHEMATICS OF FIRE PROTECTION SYSTEMS (Sheet 2 of 2)

- System II, the existing system but without optical sensors and ambient temperature compensation.
- System III, identical to System II but incorporating a newly developed actuation device for conversion of manual fire suppression systems to automatic systems.
- System IV, an alarm-only system including one or two sensors to provide an audible alarm without discharging an extinguishing agent.
- System V, a self-contained, battery-powered system using point-source sensors and the actuation device used in System III.

Various items of mobile mine equipment were selected for installation of fire protection systems: front-end loaders, coal haulers, draglines, cranes, etc.

PHASE II, INSTALLATION, MONITORING, AND DEMONSTRATION TEST

During Phase II, the systems were installed on the selected equipment at the two mine sites, as listed in Table A.

Table A AUTOMATIC FIRE PROTECTION SYSTEM INSTALLATION

Fire protection system	Jim Bridger coal mine (surface), Wyoming	Diamond Crystal salt mine (underground), Louisiana
I FMC/Bureau of Mines (original design)	Wabco 120 coal hauler	
II Without optics and thermal compensation	Caterpillar 992 front-end loader	
III Automatic/manual system	Wabco 120 ash hauler	Euclid R35 truck; Caterpillar 988 loader
IV Alarm only	Marion 8200 dragline	
V Self-contained automatic/manual system		Goodman 2500 cutter; Galion 125A crane

Diamond Crystal Salt Mine

At the Diamond Crystal underground salt mine, all vehicles were equipped with manually actuated Ansul fire protection systems. Mine management requested that Systems III and V be adapted to the existing extinguishing systems, and that electrical power be constantly and directly supplied to the fire protection systems at all times. Precautions against accidental discharge during maintenance activities were also required.

The salt mine environment adversely affected all vehicles and equipment, especially electrical connections and control circuits. Some changes in component design were necessary during the test period for systems installed

on vehicles routinely steam cleaned prior to maintenance. Three of the four systems were installed on such vehicles. The fourth system was installed on an electric undercutter which remained in the deeper, dry part of the mine and was not steam cleaned during the 11-month installation. The equipment installed on this vehicle required little maintenance.

Many events were noted during 11 months of in-mine testing. The following items are considered significant:

- Nine system activations occurred; four were intentional.
- An accidental fire in the truck starter motor completely burned the battery cable. The fire suppression system was manually activated, extinguishing the fire.
- Maintaining adequate electrical power and durable connections, free of corrosion or disconnections, was a significant problem.
- Continuous line-type thermal wire sensors required no maintenance during long-term tests. Several repairs of multiple connections and interconnecting wire on point-type thermal sensors were necessary.
- Additional seals around the main control panel and the junction box proved effective after initial problems.
- Visual indicators and other control panel components were seriously affected by corrosion. Protection was required for components of systems installed on vehicles which were routinely steam cleaned.

Jim Bridger Coal Mine

At the Jim Bridger mine, fire protection systems were installed on vehicles similar to those used in previous contract work -- vehicles with operator cabs 10 feet or more above the ground and with escape ladders passing near the engine area. A system was also installed on a Marion 8200 dragline. Mine management agreed to purchase and install one manual Ansul system to permit proper evaluation of System III. Anticipated high winds and subzero temperatures at this large western surface mine necessitated careful placement of components and incorporation of temperature-compensation features.

The following events recorded during the 10-month in-mine test were considered significant:

- Teflon seals on the two stored-nitrogen-pressure dry-powder chemical extinguishers failed to seal the 500-psi pressure when subjected to shock and vibration. Special urethane seals were installed and were effective.
- Operator and mine employee awareness of systems and components was a significant factor in successful equipment operation.
- System I, installed on a coal hauler, required little maintenance.

- Vehicle electrical systems produced interference resulting from cross voltage. The fire control system was modified to obtain power directly from the battery on the ash hauler and loader.
- Two inadvertent system discharges occurred.

FINAL TESTS

In-mine monitoring concluded with demonstrations and/or discharges of each system at each mine. Test monitoring events are summarized in Table B.

Table B SUMMARY OF MONITORING EVENTS

Mine name	Test duration, months	Total visits including installation monitoring and demonstration	Number of fire control panels replaced	Fire system activations		Replaced/repaired actuator device		Sensors failed or replaced	
				Discharged agent (includes demonstration)	Alarm - no discharge	Cartridge puncture type	Stored pressure type	Quantity	Type
Diamond Crystal mine	11	5	3	6	5	4	N/A	2	Point
Jim Bridger mine	10	6	2	4	5	0	2	1	Smoke
Total		11	5	10 ¹	10 ²	4	2	3	-

1. Seven intentional during demonstration. 2. Five not connected for discharge.

During demonstration tests, all systems responded to the test fire stimulus more quickly in the warmer, underground salt mine temperatures than in the cooler surface mine temperatures. On underground vehicles, alarms sounded within 10 to 15 seconds after fire was applied. On the surface, alarms sounded within 30 to 60 seconds due to cooler ambient temperatures and high wind conditions.

System I, with both optical and heat sensors, installed on a coal hauler at Jim Bridger mine, alarmed instantly at detection of a flame, and discharged immediately on thermal sensing. On other systems, an audible alarm and a red FIRE indicator were activated for 10 to 13 seconds before automatic discharge. System IV provided only audible/visual alarms in the operator's cab; no discharge was intended.

After the demonstrations, all systems were returned to normal working order.

CONCLUSIONS

After redesign and long-term test of the fire protection systems, the following conclusions were reached:

- Operator familiarity with the systems enhances operational performance.

- Automatic systems are well suited for use on large vehicles and where operator visibility of fire zones is impaired.
- Durable, sealed electrical connectors and additional wire protection must be used in areas subject to abuse.
- Systems with separate, isolated batteries exhibit fewer problems than systems using vehicle batteries.
- No one type of sensor application was proved superior. Vehicle electrical systems influence sensor selection.
- The newly designed cartridge-puncture valve performed satisfactorily.
- Various tests and checks can be made automatically when the system is connected through the master switch (during vehicle engine start) and manually at the operator's discretion.
- Trained personnel are needed to install and maintain the automatic fire protection systems.

RECOMMENDATIONS

Several recommendations are offered:

- Mine personnel normally assigned to work on mobile equipment should assist installation and repair of the systems to enhance their familiarity with the unique hardware of the automatic fire protection systems.
- Electrical connections and wires should be sized to meet the anticipated physical abuse normal in mining environments rather than electrical capacity requirements.
- Automatic fire protection systems should be equipped with isolated power supplies (batteries) rather than coupled to existing vehicle batteries that cause interference.
- Regular maintenance activities, steam cleaning, and washing of mobile mine equipment with automatic fire protection systems that are direct and unswitched to a power supply should be controlled.
- Controlled tests should be performed to show effects of shock and vibration on dry-powder chemical systems.
- System controls and indicators should be protected from damage caused by environmental conditions or physical abuse. Switches, circuit breakers, audible devices, and pushbuttons should be guarded or contained in such a way as to prevent physical or corrosive damage.
- Maintenance and monitoring of the automatic systems installed at the two mines should continue during an additional 24-month period.



MOBILE MINE DRILL IN FLAME CAUSING HAZARD TO
OPERATING PERSONNEL, EQUIPMENT REPAIR, AND LOST PRODUCTION

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I. INTRODUCTION AND SUMMARY

1.1 INTRODUCTION

This report presents information regarding the expansion of previous work to promote automatic fire protection systems on mobile mining equipment.

The objective of the 19-month Automatic Fire Sensing and Suppression Systems program was to design improve, fabricate, install, and test the durability of five types of automatic fire protection systems on mine equipment in production operations.

The automatic fire protection system concept and prototype hardware was first developed under two previous Bureau of Mines contracts¹ also awarded FMC Corporation:

- 1972-1973, Contract HO122053, Improved Sensors and Fire Control Systems for Mining Equipment
- 1973-1974, Contract HO232059, System Modification and Validation Testing of Fire Protection Systems for Mine Haulage Trucks.

The first contract concentrated primarily on determining severity and causes of fires in large, mobile mine equipment. It was determined that significant hazards to operators existed on large vehicles in which escape ladders pass near the engine area, the primary fire zone. Considerable losses in equipment costs and production also resulted from such fires. As a result of the study, a prototype automatic fire protection system was developed, installed, and successfully short-term tested on a 100-ton-capacity ore haulage truck.

1. Final reports are available through the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, Virginia 22161. For Contract HO122053, specify Number PB 232-406, May 1973. For Contract HO232059, specify Number PB 234-577, April 1974.

The second contract effort involved reliability and durability testing of the system previously developed while the system was installed on operating equipment in open-pit mines. The original prototype system was installed for summer testing at the Cyprus Pima mine in Tucson, Arizona, the site of the first contract work. A second, improved version was installed for winter testing on a 100-ton truck at Erie mine in Hoyt Lakes, Minnesota. At both locations, the trucks were utilized for production operations to test the durability of the fire protection systems. A series of planned fires, initiated to demonstrate the effectiveness of the fire suppression systems, were successfully extinguished automatically. One accidental fire was also effectively extinguished.

The automatic fire protection system developed during the two contracts incorporates features not previously considered for use on commercial mobile equipment but commonly used for military applications.

The following features of the system are significant:

- Multiple fire and flame sensors
- Automatic test features and fail-safe logic
- Thermal compensation.

During the performance periods of the two Bureau contracts, manually actuated fire protection systems on mobile equipment became more popular, primarily as a result of new regulating standards¹ and the low cost of a basic system typically consisting of one dry-chemical container, a propellant cartridge, and a remote actuator. Field reports indicated, however, that fast fire situations caused sufficient operator panic so that the manual actuators were occasionally not activated during a fire or were activated too late to be of consequence. Complete vehicles were then lost to the fire. Mine managers experiencing these situations promoted additional development of the original automatic fire protection system, as well as alternatives that would produce a variety of fire protection systems for different units of mobile mine equipment.

1. Code of Federal Regulations CFR 30, Part 75 (underground coal), Part 77 (surface coal), Part 55 (surface metal and nonmetal mines), and Part 57 (underground metal and nonmetal mines).

Contract HO262052 was released 21 June 1976 to design, fabricate, and test five types of automatic fire protection systems; factory test each system; and install and monitor the systems for approximately 1 year on various units of equipment in mines with different environments.

1.2 SUMMARY

The major goals of Contract HO262052 were successfully accomplished in the two phases of program activity.

During Phase I, visits to five mines located two mines of different environments willing to participate in the program: Diamond Crystal salt mine, Louisiana; and Jim Bridger coal mine, Wyoming. Five fire protection systems were identified and factory tested at the FMC Santa Clara, California, facilities. Each of the five systems, briefly, is characterized as follows:

- System I
The existing system including thermal and optical detectors, stored-pressure dry-chemical-filled cylinders, logic control, and ambient temperature compensation.
- System II
The existing system but without the optical sensors and ambient temperature compensation.
- System III
The existing system as in System II, but incorporating a newly developed actuation device for conversion of manual systems to automatic systems.
- System IV
An alarm-only system including one or two sensors to provide an audible alarm without discharging an extinguishing agent
- System V
A self-contained, automatic system using point-source sensors and the newly developed actuation device for conversion of manual systems to automatic systems.

Major components of each system are pictured in Figure 1.



Figure 1 COMPONENTS OF FMC FIRE PROTECTION SYSTEMS

Phase I activity also included selection of equipment for the systems installations at the two participating mines (see Table 1). Equipment units, one of which is shown in Figure 2, included the following:

- Front-end loaders
- Coal haulers
- Trucks
- Draglines or shovels
- Mobile cranes
- Underground electric undercutters.

During Phase II, the systems were installed on the selected equipment at each mine site. Performance of the installed systems at each mine is summarized in the following paragraphs.

Table 1 AUTOMATIC FIRE PROTECTION SYSTEMS INSTALLATIONS

Fire protection system	Jim Bridger coal mine (surface), Wyoming	Diamond Crystal salt mine (underground), Louisiana
I FMC/Bureau of Mines (original design)	Wabco 120 coal hauler	
II Without optics and thermal compensation	Caterpillar 992 front-end loader	
III Automatic/manual system	Wabco 120 ash hauler	Euclid R35 truck; Caterpillar 988 loader
IV Alarm only	Marion 8200 dragline	
V Self-contained automatic/manual system		Goodman 2500 cutter; Galion 125A crane

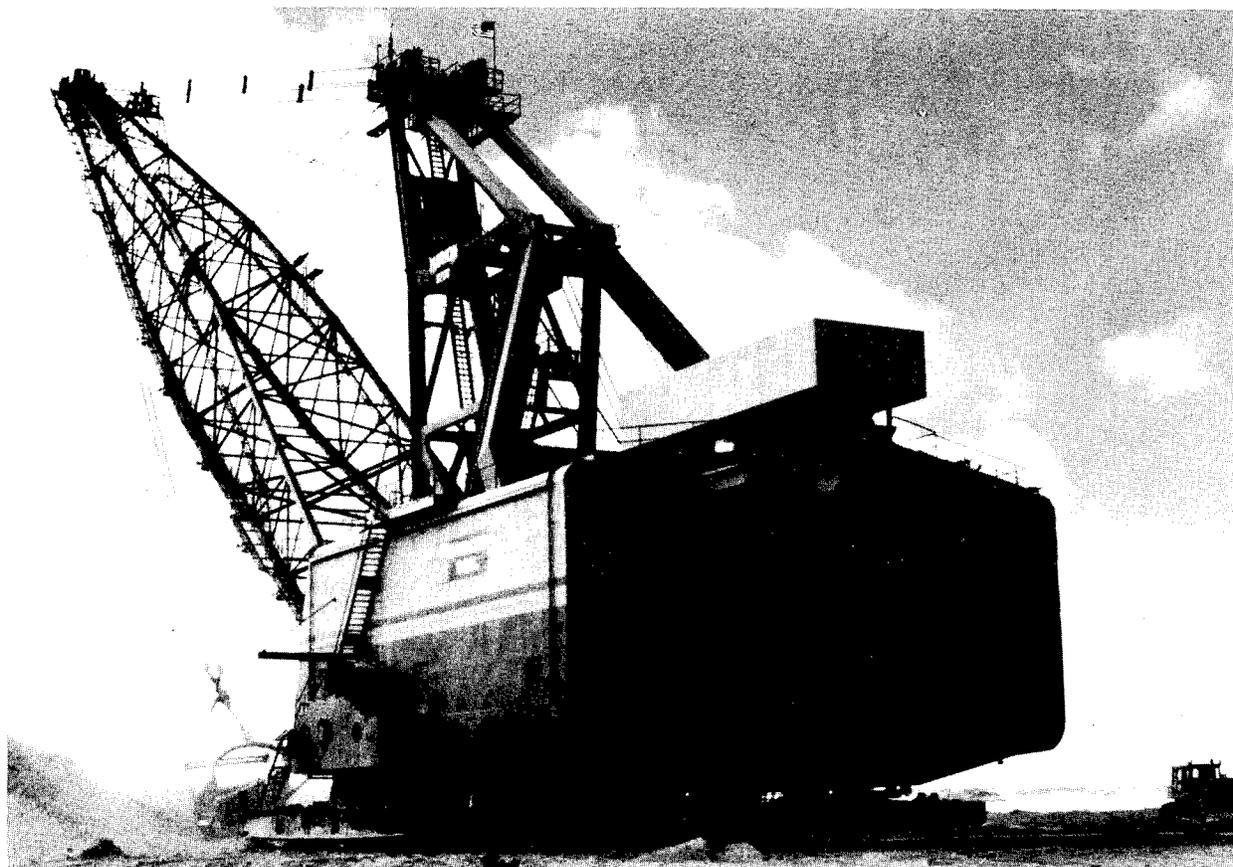


Figure 2 DRAGLINE SELECTED FOR TESTING

1.2.1 Installation, Monitoring, and Testing at Diamond Crystal Salt Mine

All mobile vehicles at the 1,700-foot-deep underground Diamond Crystal mine were equipped with manually actuated Ansul fire protection systems. Prior to this contract, mine management requested that the automatic fire sensing and discharge systems, Systems III and V, be adapted to the existing extinguishing systems. Management personnel requested that electrical power be constantly and directly supplied to the fire protection systems because fires are known to occur after engine shutdown or when the vehicle is unattended. Precautions against accidental system discharge also were necessary during maintenance activities such as welding and steam cleaning.

The salt mine environment was very severe on all vehicles and equipment, especially where electrical connections, wires, lights, switches, and circuit boards are part of the system. Three of the four systems were installed on vehicles that were routinely steam cleaned prior to maintenance. This fact required some changes in component design during the test period. The fourth system, installed on an electric undercutter, survived the durability testing with very little maintenance and rebuilding. The cutter vehicle stays in the deeper, dry area of the salt mine and was never steam cleaned during the 11-month installation.

Many events were noted during the 11 months of in-mine testing (see details in Technical Discussion, Section III). Significant events are summarized in the following paragraphs.

Nine system activations occurred; four activations were intentional during the final demonstration fire tests. One unplanned discharge occurred while starting a truck; the cutter operator reported three activations, only one of which expelled dry-powder chemical. A bent puncture pin in the actuator device failed to pierce the pressurized cartridge during one occurrence; an open air line in the Ansul system, which expelled pressure before actuating the Ansul propellant cartridge, was responsible for the second; the automatic system actuated on the third unplanned occurrence, but for unknown reasons did not expel the extinguishing agent. No false discharges were reported on the crane and front-end loader.

The truck experienced an actual accidental fire in the starter motor that completely burned the battery cable. The smoke was readily visible to the operator in the relatively small vehicle, and he activated the manual control of the Ansul system. It was determined that the automatic system did not alarm or activate because there was no sensor near the fire zone and there was insufficient heat to alarm the 260^oF set point of the automatic sensing system.

Maintaining adequate electrical power and durable connections, free of corrosion or disconnections, was a significant problem throughout the test. The two systems with self-contained batteries survived better in this respect than the systems connected directly to the terminal posts of the vehicle batteries. All systems experienced some problems with batteries having less than 18 volts (DC) available when the engine was not running. The fire protection systems were, therefore, occasionally not operational in a standby mode. Low battery voltage was attributed to lengthy vehicle downtimes and poor battery condition. Diamond Crystal mine has recently initiated use of maintenance-free batteries in several vehicles.

The continuous line-type thermal wire sensors gave no trouble during the long-term tests. The multiple connections and interconnecting wire of the point-type thermal sensors required repair on several occasions due to mechanical damage or steam, oil, or salt contaminating the connections.

Additional seals around the main control panel and the junction box proved effective after initial problems in each. Contrary to occasional practice, openings for "breathing" of electrical boxes proved fatal to electrical circuits at least three times. Three control panels had to be replaced after short duration in the harsh mine environment.

Visual indicators and other items on the control panel were also seriously affected by corrosion. Audible alarms, lights, switches, pushbuttons, and circuit breakers required protection, especially on the three vehicles subjected to routine steam cleaning (see Figure 3). No problems occurred on the automatic fire protection system installed on the cutter in the dry working area of the mine, even though salt dust accumulations were occasionally several inches thick on the components.

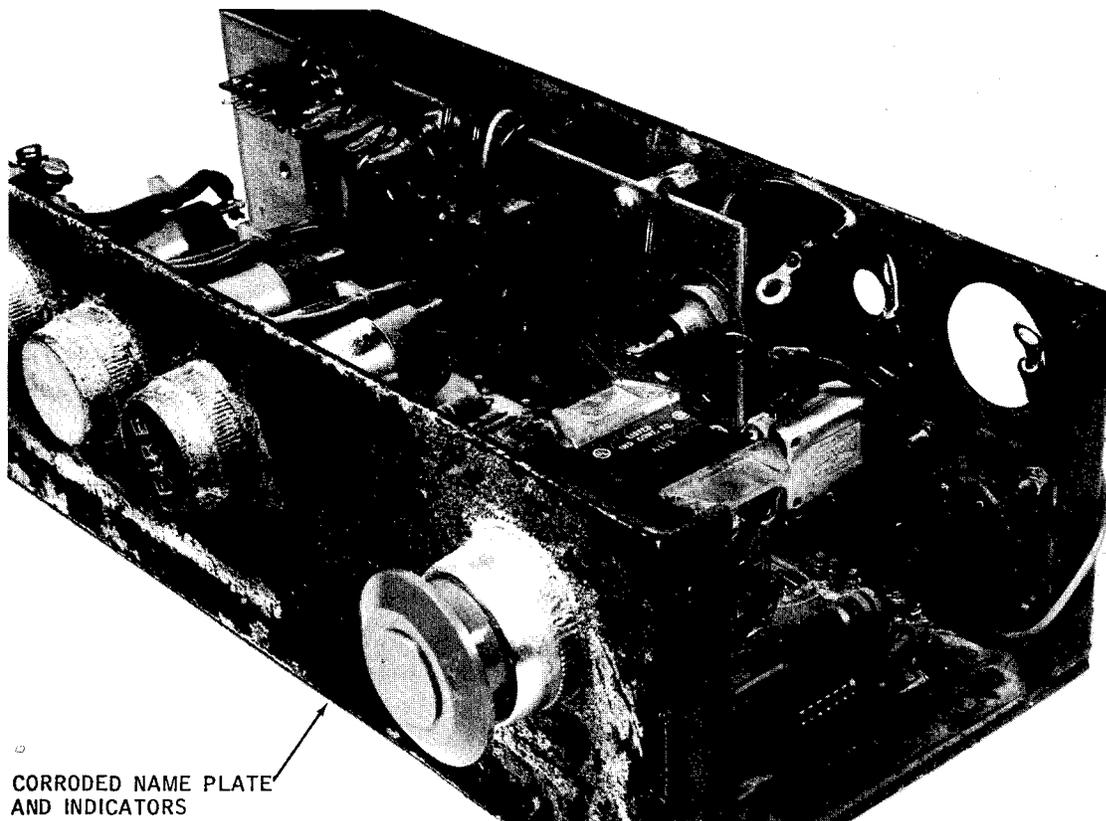


Figure 3 DAMAGE SUSTAINED BY ELECTRICAL CIRCUITS

1.2.2 Installation, Monitoring, and Testing at Jim Bridger Coal Mine

Except for the Marion 8200 dragline, the vehicles selected for installation of automatic fire protection systems at Jim Bridger mine closely paralleled those used in the earlier contracts where operators were located in cabs more than 10 feet above the ground and where the escape ladders passed near the engine area. No manual fire protection systems were installed on Jim Bridger equipment, but the mine management agreed to purchase and install an Ansul system to provide an evaluation of System III.

Environmental conditions at this large western surface coal mine were not a predominant factor as in the underground salt mine, although anticipated high winds and subzero temperatures required careful placement of system components and temperature-compensation features. The enclosed operators' cabs were relatively clean, and use of additional seals around the control units and junction boxes was not required.

Many events recorded during 10 months of in-mine testing (see details in Section III) are summarized in the following paragraphs.

The two stored-nitrogen-pressure dry-powder chemical extinguisher systems experienced valve leakage problems that required the manufacturer to fabricate special urethane seals. The original Teflon seals would not seal the 500-psi nitrogen pressure when subjected to the shock and vibrations of mining vehicle activity. The problem was recognized during Phase I, but replacement valve seals did not arrive until midway through in-mine monitoring.

Only one of the two commercial-variety smoke detectors used on the Marion 8200 unit continued to operate satisfactorily after 10 months of testing.

Both detectors were photoelectric sensors but of different construction:

- The ceiling-mounted unit experienced excessive dust collection, false-alarmed, and finally failed to operate.
- The wall-mounted unit, with a vertical circuit board, performed well throughout the 10-month test period.

Operator and mine employee awareness of the various systems and components was a factor early in the program. Systems were intentionally not connected for automatic discharge until mine personnel became familiar with display indicators and test features. Seal wires on the manual pushbuttons were often found broken until personnel became aware of the consequences.

System I, which was installed on a 120-ton coal hauler, required little maintenance during the 10-month testing period.

The durability of electrical power connections was satisfactory, but vehicle interface circuits caused interference when the lights were on and the engine was not running. This problem was experienced with Systems I and II until modifications were incorporated to bypass the master switch, thus routing 24-volt DC power directly from the battery to the system (as was done with all Diamond Crystal systems).

Only two inadvertent system discharges occurred. It was initially considered that the ash hauler truck with the automated Ansul system was activated and discharged without apparent operator awareness. It was thought that engine noise overrode the audible alarm, and the dust condition generated by the dry-chemical powder system discharge was unnoticed due to similarity with the standard heavy dust conditions of surface mining. The yellow FAULT light indicated an open circuit breaker to the solenoid valve, an event that occurs when the system is activated electrically. Investigation of the cause of the discharge revealed a broken seal wire on the manual pushbutton indicating manual rather than automatic discharge.

The second unplanned discharge, on the front-end loader, was reported as a partial discharge because only one of the two cylinders was empty on inspection. The push-to-discharge manual button was sealed properly, but the manual operator lever on the solenoid valve appeared damaged.

1.2.3 Final Demonstration Tests

With the exception of the Caterpillar 992 front-end loader at Jim Bridger mine, which was not available for the tests, each system at each mine was demonstrated and/or discharged to conclude the in-mine monitoring efforts (Figures 4 and 5).

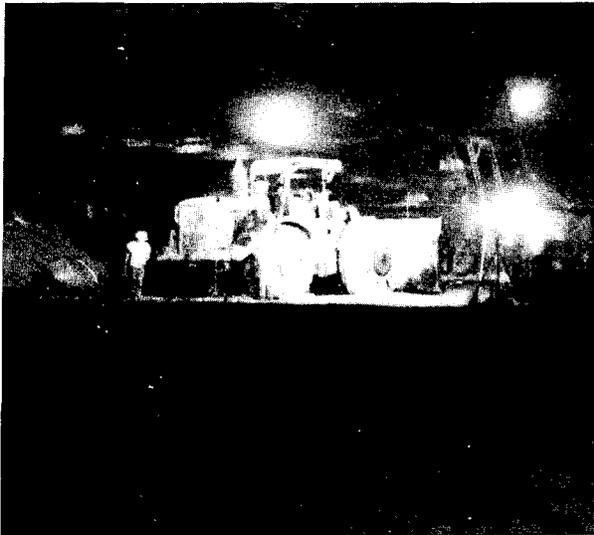


Figure 4 FIRE TEST DEMONSTRATIONS AT DIAMOND CRYSTAL MINE

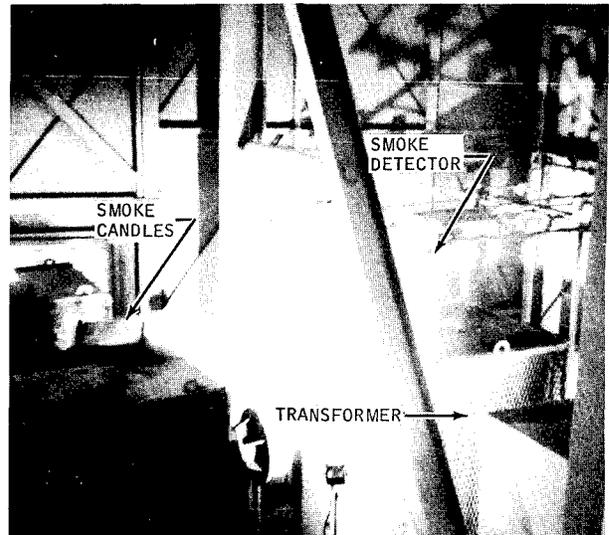


Figure 5 SMOKE TESTS ON MARION 8200 DRAGLINE (JIM BRIDGER MINE)

The test stimulus at each mine was flame and heat from a burning kerosene-soaked cloth except for the dragline tests in which smoke candles were placed in a pan.

All the systems responded more quickly in the 95° F ambient temperature of the underground salt mine than during 50° F temperatures and the high wind conditions at the surface installation. At Jim Bridger mine, System I, with optical sensors, alarmed instantly at the detection of the test fire flame, but discharge was not activated until thermal heating occurred in the ambient-temperature-compensated, 260° F set point continuous wire sensor. The 30-second response time was 50 percent better than that of System III, which does not incorporate temperature compensation. Fire alarms sounded on the underground vehicles within 10 to 15 seconds after the test fire was applied. During the surface tests, the alarms required three to five times this length of time to sound.

By the inherent design, System I, installed on a coal hauler, was the only system to discharge immediately on thermal sensing. The optical sensors gave immediate visual/audible alarm of the test fire flame, and, once the heat was sufficient, discharge was simultaneous with the new alarm. All other systems provided a 10- to 13-second visual/audible FIRE alarm after heat sensing and prior to automatic discharge. The smoke-candle tests on the dragline provided only a visual/audible alarm in the operator's cab, as System IV was not intended to discharge an extinguishing agent. Carbon dioxide extinguishing systems with pneumatic heat sensors had previously been installed by the mine personnel in areas where the smoke sensors were being trial tested.

After the demonstrations, all systems were rebuilt and returned to normal working order. Some modifications, which were noted as desirable during the tests, were incorporated at this time. For example, a hinged guard was installed over the manual actuator buttons to prevent accidental manual actuation of the systems at Jim Bridger mine.

1.3 COST GUIDE

Component estimated price ranges are as listed in the following paragraphs. The estimated costs are for the basic unique elements and do not include installation labor costs nor costs for minor installation hardware such as hoses, fittings, and special brackets. The estimated costs are based on 1978 prices. Different purchase quantities account for the price range.

For System I, one logic control panel with molded cable; four optical flame sensors with molded cables; one 16-foot thermal sensor element with two cables; one junction box assembly; one temperature-compensation sensor with molded cable; and two high-pressure containers with valves, chemical housings, and eight nozzles are required, at a cost of approximately \$2,500 to \$5,000. System I utilizes 24-volt DC vehicle power.

For System II, one logic control panel with molded cable; one 16-foot thermal sensor element or six point heat sensors; one junction box assembly; and two high-pressure containers with valves, chemical housings, and eight nozzles are required, at a cost of approximately \$2,000 to \$4,000. System II utilizes 24-volt DC vehicle power.

For System III, one logic control panel with molded cable; one 16-foot thermal sensor element or six point heat sensors; one junction box assembly with relay; and one cartridge actuator device are required, at a cost of approximately \$1,500 to \$3,000. System III utilizes 24-volt DC vehicle power and the existing fire suppression system.

In System IV, one logic control panel with 110-volt AC cord and two photo-electric smoke sensors with 110-volt AC connections are required, at a cost of approximately \$500 to \$1,500. System IV utilizes 24-volt DC vehicle power.

For System V, one logic control panel with molded cable; one 16-foot thermal sensor element or six point heat sensors; one junction box assembly with relay; and one cartridge actuator device are required, at a cost of approximately \$1,800 to \$3,500. System V utilizes self-contained 24-volt DC batteries and the existing fire suppression system.

II. CONCLUSIONS AND RECOMMENDATIONS

2.1 CONCLUSIONS

The redesign of the original automatic fire protection system and the multiple long-term testing of five different systems permit the following conclusions:

- Operator familiarity with the systems enhances system performance by decreasing the number of accidental discharges. System reliability is thereby more easily evaluated.
- Automatic systems appear more advantageous on larger vehicles or when operators and personnel cannot see or otherwise observe the fire zones.
- Performance of battery power and other electrical connections were significant during tests in both mines. Durable, sealed connectors are required, as are rigid and flexible conduits where excessive mechanical abuse is evident.
- Vehicles having separate, isolated batteries exhibited fewer vehicle interface problems, but will require special charging systems. The batteries were often discharged because the vehicle was out of service for extended periods.
- Type of sensor application remains optional. The thermal-wire sensor experienced no problems; however, extreme care was exercised for added protection during installation. The point-type sensors are less expensive initially but provide service over a smaller area. Also, on one of three vehicles with point sensors, considerable maintenance was required.
- Different vehicle electrical systems will influence sensor selection. Battery ground was through the master switch on both front-end loaders thus requiring isolation (float) fire sensing components, including the thermal sensors. Point sensors were used in these installations because the inherent condition of the outer sheath is ground on the continuous thermal-wire sensors.

- The stored-pressure, dry-powder chemical extinguishing system was unfamiliar to maintenance personnel. Rebuilding of components requires additional time in a relatively clean environment. The possibility of rebuilding a contaminated solenoid valve in the field is doubtful.
- Although less time is required to refurbish manual discharge, cartridge-actuated fire protection systems, integrity of components must be checked periodically to assure adequate performance, especially where severe environmental conditions exist. Open pressure lines, discharged systems, or packed dry-powder chemical were evident on several occasions.
- The newly designed cartridge-puncture valve performed marginally during the long-term test. Tolerance adjustment during assembly was critical, solenoid power rating was considerable, and the puncture pin bent once during resetting.
- The logic design permits making various tests and checks automatically (during vehicle engine start) when connected through the master switch and manually at the operator's discretion. Manual testing requires a conscious effort on the part of interested personnel or direction from a checklist. Whereas inadvertent failures of the manual, nonautomatic fire protection systems will likely be undetected, tracing fault areas on an automatic system is quickly accomplished by moving the test switch. Wire continuity, connections, and cylinder pressures are known immediately.
- Trained persons are required for installation and maintenance of the automatic fire protection systems. Any periodic events that cause the yellow FAULT light to appear must be corrected by persons familiar with the system(s), who are able to interpret electrical schematics, who are qualified to handle pneumatically pressurized vessels, and who have access to and knowledge of a volt-ohmmeter.
- Precautions taken during systems installations allowed for minor preventive maintenance or complete engine removal without disturbing the fire protection system components or causing added maintenance. Most wiring and plumbing was secured or routed to fixed structural members. Nozzles or sensors on engine covers experienced only a few disconnects and all were easily accessible.

2.2 RECOMMENDATIONS

Several recommendations are offered as a result of experience gained during the redesign of the original system and the 11-month in-mine testing of eight automatic fire protection systems:

- Specific personnel normally assigned to work zones around the mobile equipment should be assigned to assist installation and repair of automatic fire protection systems on mobile vehicles. Responsible persons should also enact a training and information session, perhaps during regular safety meetings, to inform all operators and personnel of the unique features of the systems.
- Local, state, federal, and other regulating or standards-generating agencies should become proficient in application and use of fire sensing and suppression systems on mobile mine equipment. Standards for the mining industry are vastly different from those established for other industries. Laws and standards should be carefully weighed against real needs before enactment. For example, not all 100-ton ore haulage trucks have operator escape ladders passing the fire-prone engine areas. Nozzle placement, hose blockage, continuity tests, and fires during rollover are other factors to consider.
- An evaluation of fire type and intensity relative to selection of an extinguishing agent and application of a system would guide designers and installers of fire protection systems. For example, 1 pound of dry-powder chemical per square foot of surface area produces considerably different results if the fire is a pool of burning liquid, a foam seat cushion, a burning tire, or a pile of rubber hoses.
- Electrical connections and wires should be sized to meet the anticipated mechanical abuse normal in mining environments rather than electrical capacity requirements. Environmentally sealed units requiring few disconnects are more likely to survive longer than systems having multiple disconnects.
- Automatic fire protection systems with isolated battery supplies appear less troublesome than systems coupled to existing vehicle batteries. Recharging capabilities of the isolated battery must be maintained. Changing the three incandescent bulbs in the control panel to light-emitting diodes (LEDs) would aid in reducing power consumption.

- Regular maintenance activities, steam cleaning, and washing of mobile mine equipment with automatic fire protection systems that are direct and unswitched to a power supply should be controlled. Consequences of accidental discharge during normal mine activities, which are other than true fire situations, should be reviewed.
- A series of controlled tests should be performed to show effects of shock and vibration on dry-powder chemical systems. Both stored-pressure systems and cartridge systems should be trial installed on mobile mine equipment and undisturbed for at least 12 months. Positioning the containers in vertical, 45-degree, 90-degree, and 180-degree positions should also provide interesting and relative data.
- The newly designed cartridge-puncture solenoid valve should be product improved to allow interchangeability of solenoid coils without tolerance buildup and interference. The puncture pin should be strengthened to avoid bending, and the relatively small and easily damaged (1/8 NPT) threads should be avoided.
- System controls and indicators should be protected from damage by environmental conditions or mechanical abuse. Switches, circuit breakers, audible devices, and pushbuttons should be guarded or contained in such a way as to prevent damage.
- Maintenance and monitoring of the automatic fire protection systems installed at the two mines should continue during an additional 24-month period. A ledger should be maintained to record events as they occur on each vehicle system so that the Bureau of Mines and mine industry can become better informed of systems performance.

III. TECHNICAL DISCUSSION

The contract for automatic fire sensing and suppression systems for mobile mining equipment involved the following objectives:

- Design, fabricate, and factory test five types of automatic fire suppression systems.
- Install the systems on various units of mining equipment at operating mines and monitor performance for 1 year.

Designs of the systems were to be based on prototype hardware conceived, fabricated, and tested under Bureau of Mines Contracts HO122053 and HO232059.

3.1 DEVELOPMENT OF VEHICLE FIRE SUPPRESSION TECHNOLOGY

3.1.1 Bureau of Mines Contracts HO122053 and HO232059

In June 1972, the Bureau of Mines released Contract HO122053, Improved Fire Sensors and Control Systems for Mining Equipment, to perform the following tasks:

- Study the fire problem on large mobile mining equipment in which the operator is positioned at least 10 feet above the ground.
- Identify mine equipment most prone to fire.
- Design an improved fire protection system.
- Install and demonstrate the developed system.

After visiting ten mines and seven truck manufacturers, analyzing returns of 303 questionnaires, and compiling data on 990 units of large mobile mining equipment, large haulage trucks were identified as the prime candidates for a fire protection system (see Figure 6).

While haulage trucks represented 66 percent of the equipment units in the survey sample, they were involved in 76 percent of fires (see Table 2).

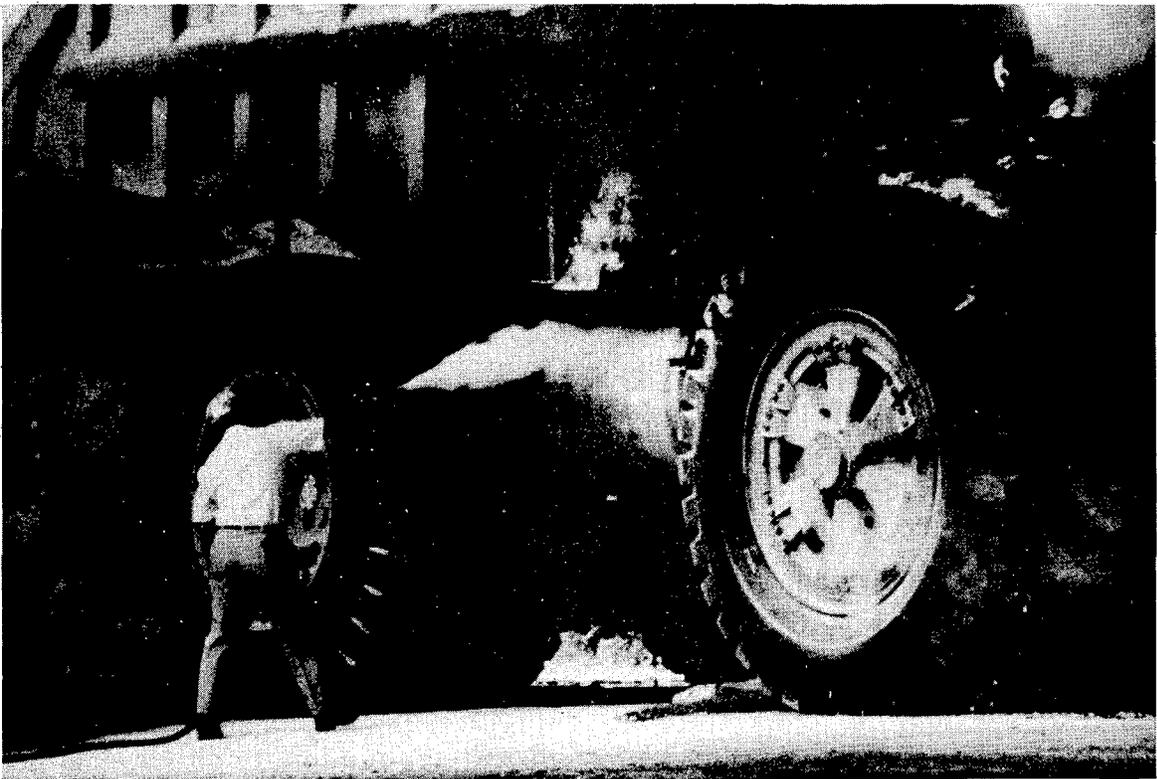
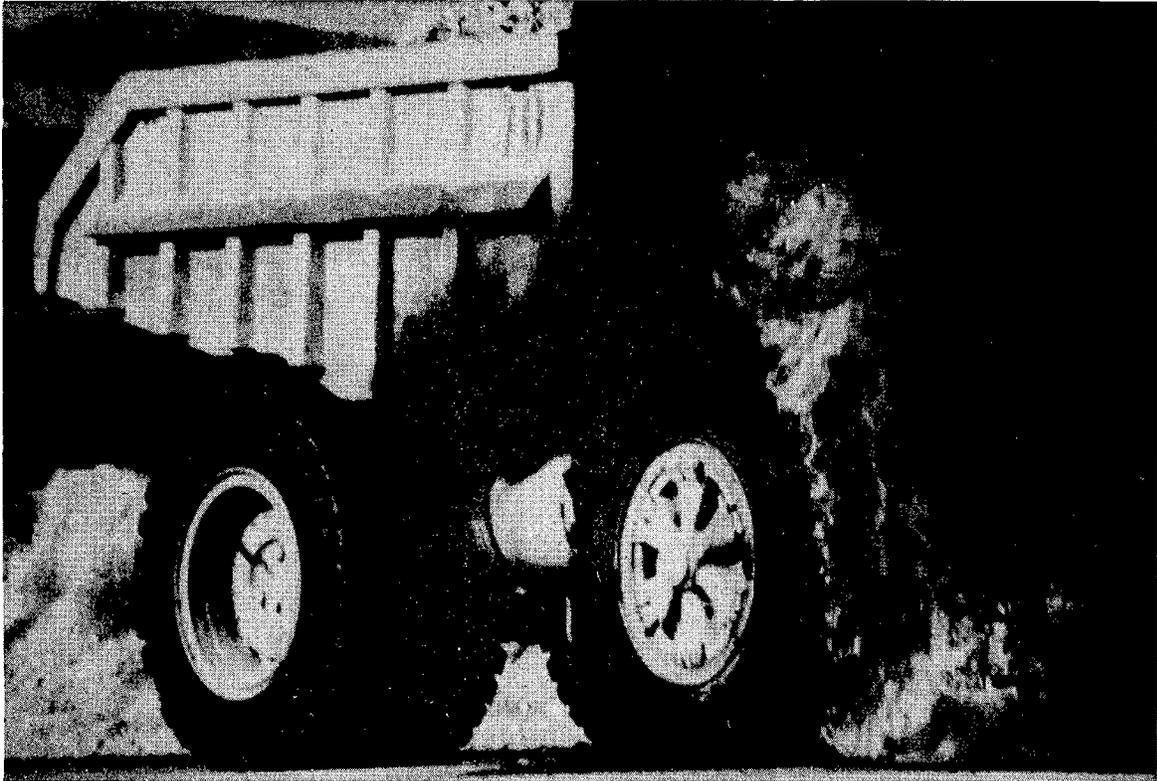


Figure 6 FIRE ON 100-TON TRUCK

The trucks thereby experienced the greatest ratio of fire per unit of equipment. Further analysis, summarized in Table 3, identified the most common causes of fire on haulage trucks.

Table 2 SURVEY RESULTS, NUMBERS OF EQUIPMENT FIRES

Type of equipment	Number in sample	Percentage of total number	Number of fires	Percentage of total number	Ratio: Fire Equipment type
Trucks	655	66	134	76	0.20
Shovels	182	18	33	19	0.18
Other	153	16	9	5	0.06
Totals	990	100	176	100	

1. Numbers include data collected from visits to mine personnel and from questionnaire responses.

Table 3 CAUSES OF FIRE, LARGE HAULAGE TRUCKS

Fire cause	Number of fires	Percentage of total number
Hydraulic fluids	49	37
Electrical	22	16
Mechanical	20	15
Antifreeze and housekeeping	16	12
Engine lubrication oil	16	12
Fuel	11	8
Total	134	100

From the analysis results, the following design criteria were established for an automatic fire protection system:

- Fire sensors must be reliable and as fail safe as possible.
- One type of sensor must provide immediate warning of flash fires.
- Some degree of redundancy should be included in case of sensor failure.
- The total system should incorporate a self-checking feature, and should monitor broken or disconnected wires.

- Use of sensors with rate-of-rise features will provide fast warning of fire and will diminish fire damage.
- Indicators should visually relate the integrity of the system; e.g., open wires, lost pressure, empty cylinders.
- Automatic dry-chemical discharge, engine shutdown, and automatic application of brakes features are desirable only where safety during such events can be guaranteed.
- Components should be designed for severe service, shock, vibration, and temperature extremes ranging from -50°F to 130°F .
- Only state-of-the-art components should be selected.
- All system components should be reasonably priced and easily installed, maintained, repaired, and recharged.

A first-prototype system of the truck fire protection system was assembled, fire-tested on a full-size mockup of a 100-ton truck, and then installed and successfully fire-tested on an actual production vehicle at the Cyprus Pima mine in March 1973. The system tested consisted of the following components:

- Two high-pressure cylinders containing 20 pounds of dry chemical and 500 psi of dry nitrogen
- Four optical flame sensors and two thermal-wire heat sensors
- Logic circuits to test wire continuity, delay discharge, and check cylinder pressure.

"Fire Protection System" Patent 3,993,138 was issued 23 November 1976 as a government-owned invention available for licensing in the United States (and possibly in foreign countries). The patent includes 15 claims, several of which have since been related to commercial radiation sensors that continuously pulse-test the integrity of the optical detector system (e.g., Detector Electronics Corporation automatic optical integrity systems).

Because of the limited exposure of the first-prototype fire protection system, a second contract, Bureau of Mines Contract HO232059, Truck Fire Protection Validation, was granted in June 1973 to conduct further development, technical improvements, and validation testing of the

automatic fire protection system. The original system was reinstalled on the 100-ton truck at Cyprus Pima mine (copper), and 2,103 hours of operation were accumulated during 4 months of hot-weather testing when ambient temperatures reached 105°F. An improved system was also installed on another 100-ton truck at the Erie mine (taconite) in Hoyt Lakes, Minnesota, for 6 weeks of cold-weather testing in ambient temperatures as low as -37°F.

Successful testing and discharge demonstrations, including one discharge that automatically extinguished an accidental fire on the Arizona test vehicle, concluded this program in April 1974.

Changes from the original system incorporated into the improved system included the following:

- Increase of dry chemical to 25 pounds in each pressurized cylinder.
- Incorporation of molded electrical connectors for environmental protection of major components.
- Elimination of the junction box by combining all electrical functions on a new printed-circuit board and connecting it to a multiconductor cable.
- Adding an ambient temperature-compensation circuit to lower the sensor alarm set point in cold climates.
- Deletion of the 615°F thermal wire sensor which was installed in the brake grid area; retention of engine area thermal wire with a 260°F alarm set point.
- Change in logic circuitry to allow complete automatic discharge, without delay circuit, if the optical flame sensors and the thermal sensor are in alarm simultaneously.

The general arrangement of components on a truck is shown in Figure 7. Actual hardware and an interconnecting diagram are shown in Figure 8.

3.1.2 Industry Acceptance of Fire Protection Systems

Although automatic fire protection systems for mobile vehicles date back to the late 1950s when such systems were tested for use on military vehicles, the initial effort to incorporate similar systems into mining equipment in the metal and nonmetal mining industries began in 1972.

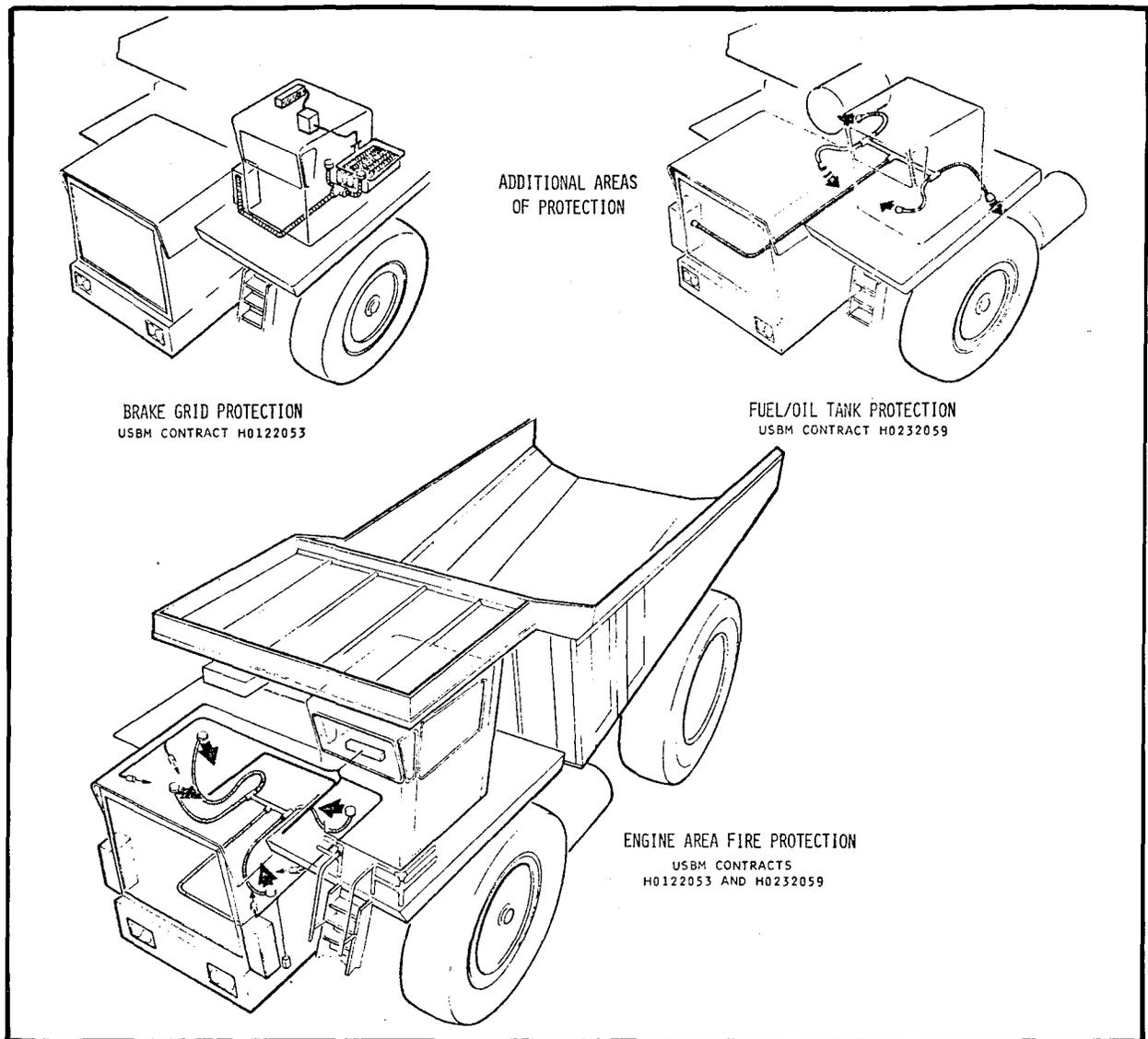


Figure 7 SYSTEM MODIFICATION AND VALIDATION TESTING OF AUTOMATIC FIRE PROTECTION SYSTEMS FOR MINE HAULAGE TRUCKS

Various sensors, extinguishing agents, and logic control systems have been trial tested, both individually and in combination with each other, to determine systems that will meet the established needs. Also, new components and systems are being researched, tested, and developed.

During the Vietnam conflict, even the fast response of pressure and radiation (light) sensors could not detect land mine and rocket penetration fires in fuel cells and adequately disperse the extinguishing agent (Halon 1301) in time to quench the rapidly propagating fire. As a result of these problems, the wire-grid shield was developed for military vehicle explosion suppression.

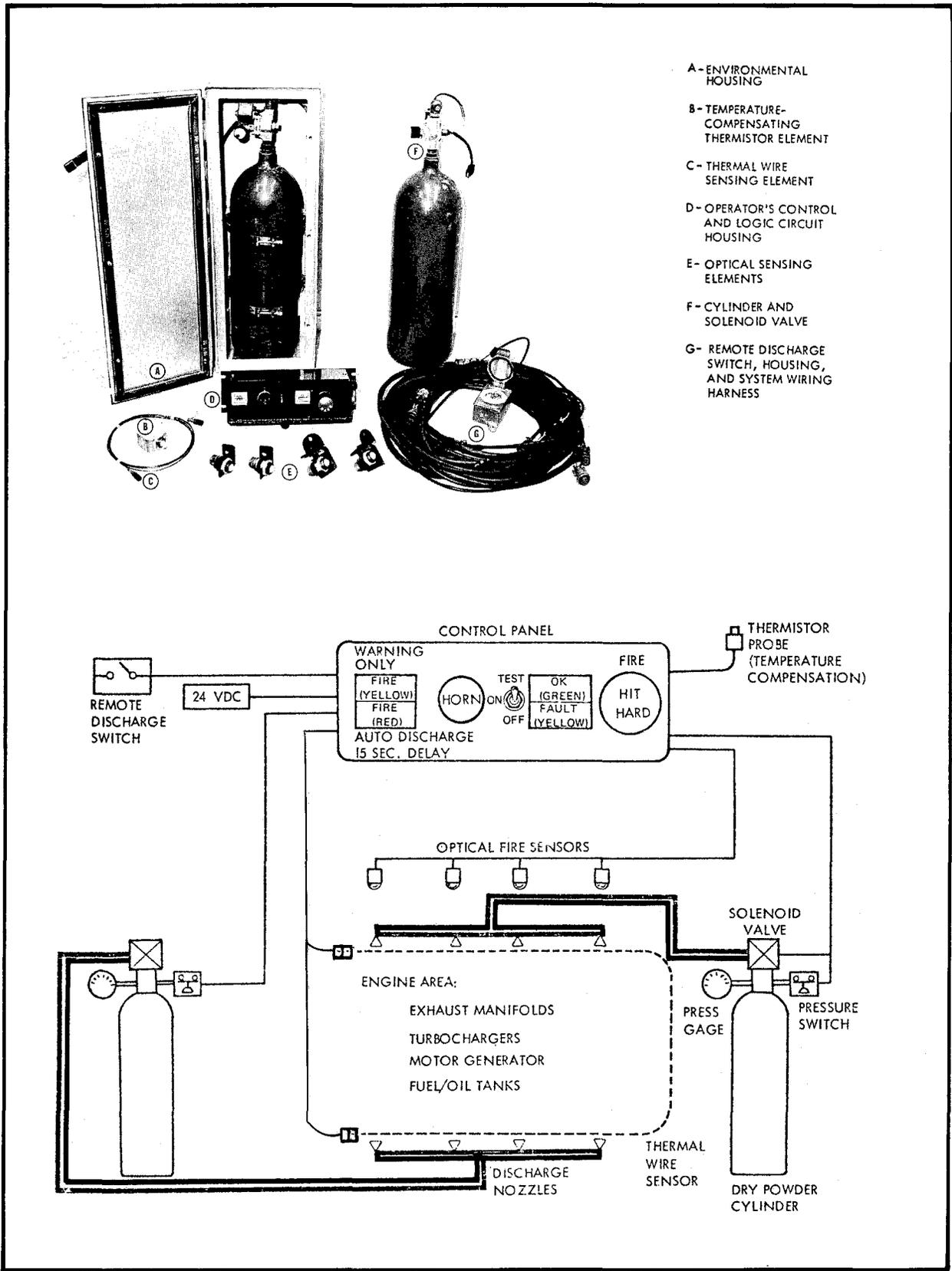


Figure 8 AUTOMATIC FIRE PROTECTION SYSTEM, SECOND PROTOTYPE

When placed around fuel tanks, the shield detects penetration and quickly starts the chain-reaction process that discharges the Halon. This system has proven effective, although the wire grids are bulky and occasionally maintenance-prone. Efforts are being made to substitute small, selective-wavelength, infrared optical sensors for the grid shield. Two or four of these sensors could potentially replace the wire grid shields.

The same mulitwavelength infrared optical sensor was chosen as the optimum sensor for mobile mining equipment during Contract HO122053. Because of increased costs, procurement lead times, and development risks, however, the unit was not approved. Two sensor types were selected:

- Photoresistance-type optical sensors
- Continuous-wire thermal sensors.

The optical sensors selected are less expensive, but are prone to occasional false alarms. They provide fast (millisecond) detection of rapidly spreading fires. A 16-foot-long continuous-wire thermal sensor was used for redundancy and detection of slowly growing fires. The two sensor types and the logic of their interconnection with other portions of the total system (i.e., thermal compensation, nitrogen-stored dry chemical, etc.) were successfully demonstrated during Contracts HO122053 and HO232059.

Various industries, particularly the mining and construction industries, commonly use mobile vehicles ranging in size from 35 to 170 tons capacity. Corresponding costs range from \$50,000 to \$500,000. Although a need exists with these large expensive vehicles for automatic fire sensing and extinguishing systems, the industries have been reluctant to install systems. The following factors contribute to this reluctance:

- Many fires are extinguished by portable extinguishers when personnel are present and observe the fire in time.
- Individual industries have a history of low incidence of fire. Many fires are unreported, however, and actual costs are frequently hidden.
- Portable or fixed manual-release systems are less expensive and require less maintenance than the automatic systems, although the cost of an automatic system is approximately 1 percent or less of the vehicle cost and the system offers protection regardless of operator actions.

- New legislation may change the need or requirements and make a purchased system noncompliant with regulations.
- There are relatively few suppliers of automatic systems.

Because several mines have experienced vehicle/equipment fires that have not been extinguished by onboard portable extinguishers or by fixed manually actuated systems, mine management has promoted further development of automatic systems. Operator panic during fire, although unpredictable, frequently is associated with the severity of a fire and poses a particular hazard to the operator. When a significantly fast-flaming fire occurs, operators abandon the vehicle, occasionally without actuating the manual extinguisher release (if one exists). The fire then grows to ignite secondary combustibles (i. e., tires and hoses), rendering the onboard extinguishing systems useless (see Figure 9).

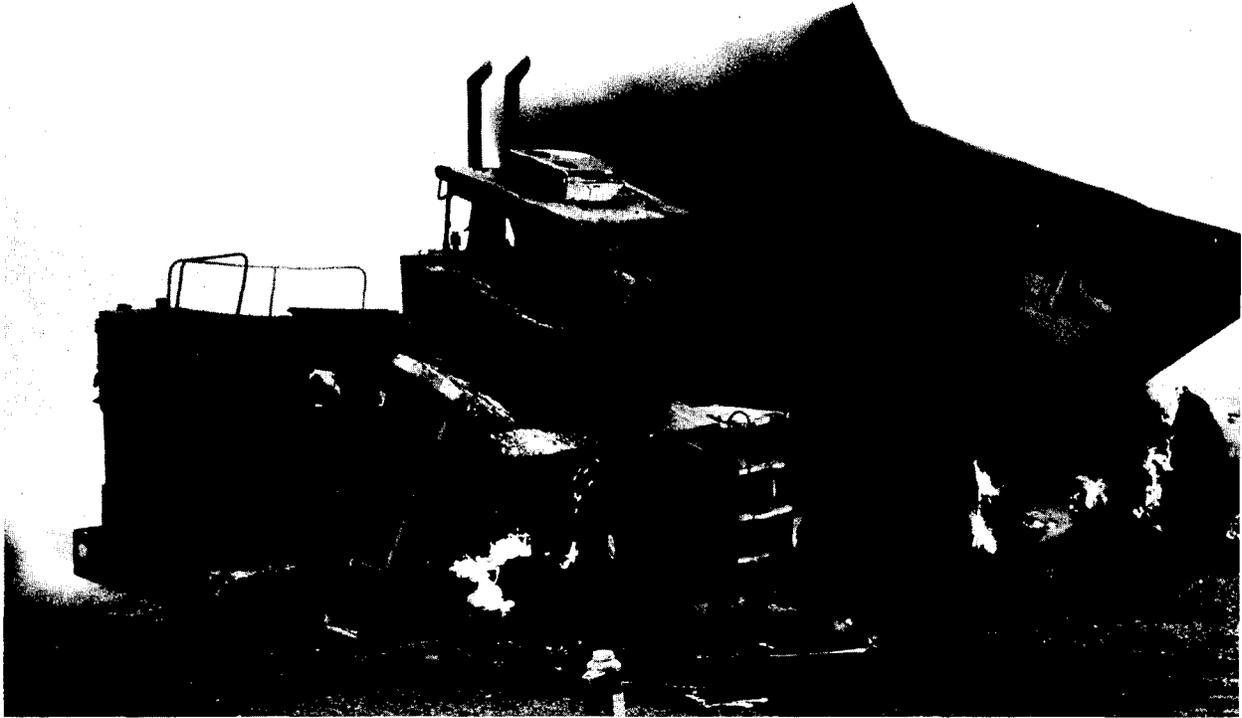
Mine management has expressed particular interest in the continued development of automatic fire protection systems that can be applied to a variety of vehicles.

3.2 PHASE I PROGRAM PLAN

The required Phase I Program Plan (Appendix A) was submitted as part of the first monthly report, July 1976. This plan provided the details of the contract, a test schedule, and interconnection diagrams of the proposed five fire protection systems. The program schedule is shown in Figure 10.

Not included in the Program Plan were letters of intent (Contract Requirement Paragraph 1.1) and firm commitments (Contract Requirement Paragraph 1.2) from each of three test mines. Although several mines had been contacted by telephone prior to contract award and letters of intent had been received, contacting different mines was necessary because of changing interests among mine managers between initial contact and followup efforts. It thus was not feasible to include commitments from mines in the Program Plan 30 days after contract award.

As scheduled, Bureau of Mines technical project personnel visited FMC within 2 weeks of contract award to confirm all contract goals and procedures.



Truck Fire



Front-End Loader Fire

Figure 9 TYPICAL VEHICLE FIRES IN WHICH PORTABLE OR MANUAL FIRE PROTECTION SYSTEMS FAILED TO EXTINGUISH THE FIRE

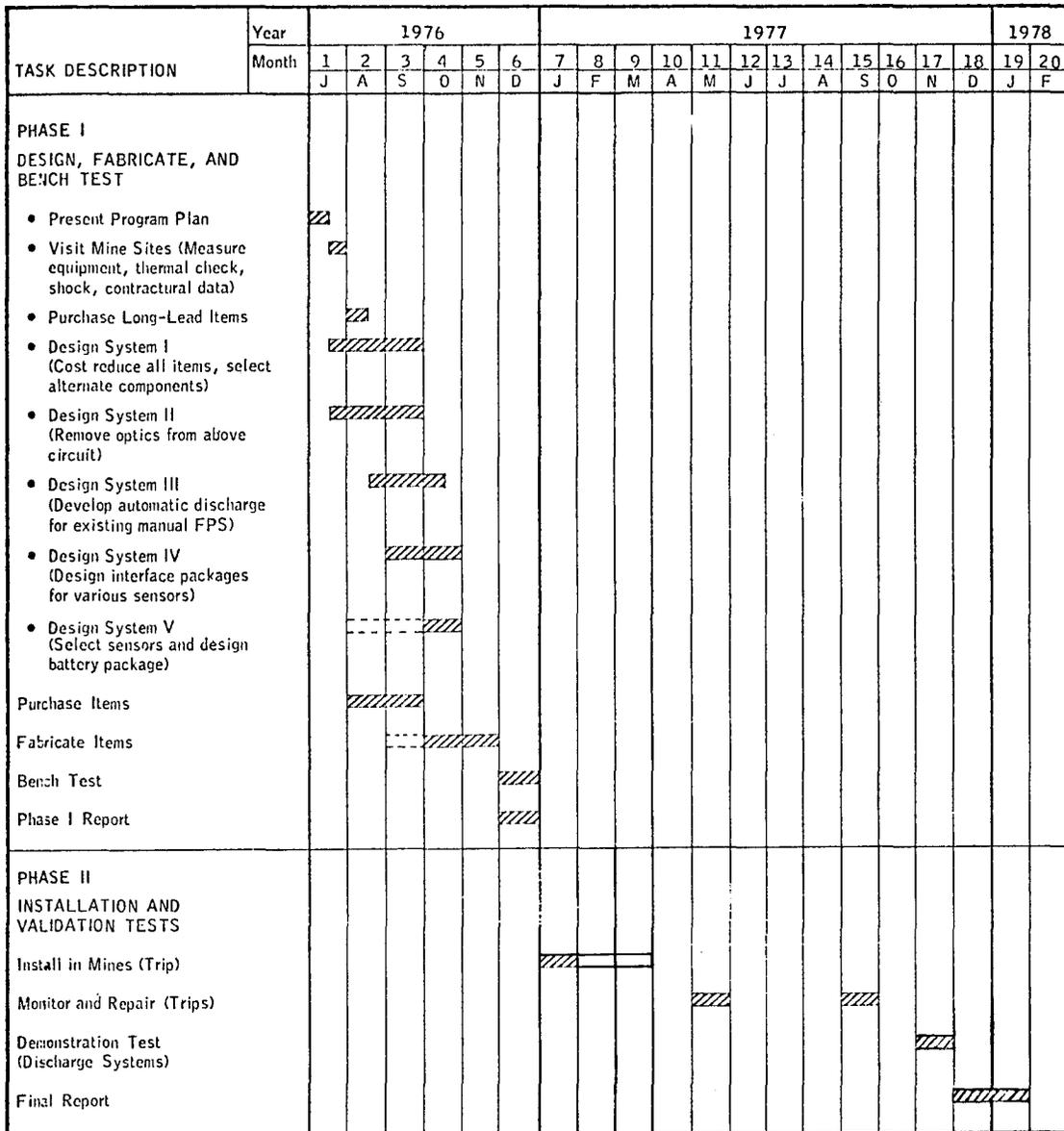


Figure 10 SCHEDULE OF PROGRAM FOR AUTOMATIC FIRE SENSING AND SUPPRESSION SYSTEMS ON MOBILE MINE EQUIPMENT

3.3 MINE VISITS

Five mine sites and a Midwest regional office of another large mine company were visited during the first 3 months of the contract. The first mine, visited 23 June 1976, was a large strip-mine operation (coal) in the northwestern section of the United States. Mine operators expected receipt of four new 120-ton coal-haulage trucks and were very interested in installing and testing the FMC/Bureau of Mines automatic

fire protection systems. They also expressed strong concern for fire protection during vehicle rollover and improved fire protection and extinguishing of fires in bulk storage piles.

Because contract compliance required installation of the automatic fire protection systems on many types of mobile mine equipment (not only trucks), a search for another mine site was conducted.

On 24 June 1976, a second mine was visited. This mine was a large western, open-pit copper mine whose management had earlier expressed an eagerness to participate in the contract test effort. Again, fire protection of new trucks was the main interest, and other equipment was not offered. Installation assistance also was not available. This mine was therefore not considered as a potential test site.

A third mine visit, 31 August 1976, was to a large northwestern strip mine. This mine had performed previous contract work for FMC and expressed strong interest in maintaining working relations by installing and testing FMC/Bureau of Mines fire protection systems wherever possible. Four mine vehicles, which satisfactorily met the contract goals, were offered for the long-term tests, as was a subcontract for a cost-sharing effort.

A fourth mine visit, 30 September 1976, was to a previously committed underground salt mine in the southern United States. The unique applications and severe service needs anticipated at this mine provided the opportunity for evaluation of hardware durability. Mine management desired installation of a system on an electric undercutter that would require adding 24-volt DC battery packages, a power converter, and a charger. Management of this mine also expressed interest in having the systems active at all times, not connected to the vehicle master switch. The mine personnel agreed to provide the vehicles and the labor assistance required to install the fire protection systems on a cost-sharing contract basis.

The fifth mine visit, 4 December 1976, was to a large midwestern strip-mine operation. The offer of a variety of equipment and the mine's geographic relationship to another candidate mine appeared to help satisfy all contract constraints (i. e., costs, time, etc.).

During visits to this area, a regional office of another large coal mine company was visited, and similar interest in conducting the test demonstrations was expressed. Because personnel of three of the mines visited previously had verbally expressed acceptance of the program and satisfactorily met all contract goals by offering equipment and installation assistance, negotiations with this mine company were not pursued.

Contractual statements of agreement to participate in the installation and testing of the automatic fire protection system were forwarded to each of the participating mines.

3.4 MINE EQUIPMENT FOR SYSTEMS INSTALLATION

The various units of mine equipment selected for installation of the contract-developed automatic fire protection systems offer a range of applications of the basic technology gained during previous Bureau of Mines Contracts HO122053 and HO232059. Table 4 identifies the equipment selected at each candidate mine.

Table 4 PLANNED EQUIPMENT INSTALLATIONS AT CANDIDATE MINES

Fire protection system	Mine name, equipment		
	Diamond Crystal salt (underground), New Iberia, Louisiana	Jim Bridger coal (surface), Rock Springs, Wyoming	Third candidate mine
I FMC/Bureau of Mines (original design)		Wabco 120 coal hauler	Michigan 380 wheel bulldozer
II Without optics		Caterpillar 992 end loader	Terex TS-24 tractor/scrapper (point sensor)
III Automatic/manual system	Euclid R35 truck	Wabco 120 coal hauler	Kress coal hauler
	Caterpillar 988 end loader		
IV Alarm only		Marion 8200 dragline	Bucyrus-Erie 9W dragline
V Self-contained automatic/manual system	Goodman 2500 cutter Galion 125A crane		

It was anticipated that each vehicle would require specialized installation, requiring minor modification of a given system. Significant aspects anticipated for each installation were as itemized:

- Wabco 120 coal hauler
This tractor/trailer vehicle is most similar to previous installations.
- Michigan 380 wheel bulldozer
Rear-engine application with less room and possibly higher-heat areas may require alteration of sensor location or alarm set point.
- Caterpillar 988 and 992 front-end loaders
Installation alterations similar to those required for the Michigan bulldozer may be needed. Furthermore, if the vehicle electrical negative ground is through the master switch rather than through the frame and if mine operators desire nonswitched fire protection systems, thermal point sensors must be used rather than the line-type thermal wire sensor.
- Terex TS-24 tractor/scrapper
Having a dual-engine (front and rear), the Terex unit will require isolation of heat sensors to respond selectively to fire situations in each area.
- Euclid R35 truck
Possibly equipped with a positive ground, the Euclid 24-volt DC vehicle may require the addition of power inverters or a separate 24-volt DC alternator.
- Galion 125A crane
The Galion 12-volt DC vehicle will require a system application similar to those for the Euclid and Kress vehicles.
- Kress coal hauler
The remote rear-engine configuration and 12-volt DC electrical system of the Kress coal hauler result in application specifications similar to those for the Euclid and Galion vehicles.
- Goodman 2500 cutter
The Goodman electrically powered undercutter is used in an underground salt mine with severe environmental conditions. Fortunately, the 110-volt AC power available for lighting allows minor conversion for the 24-volt DC fire protection system.

- Marion 8200 dragline

Two areas of the Marion dragline selected for early fire warning system installations are the large oil storage compartment and a power transformer. These areas are now equipped with heat sensing devices and carbon dioxide extinguishers; the durability and effect of photoelectric smoke sensors will be evaluated during the 12-month test period. Sensors will be connected to the 110-volt AC alarm panel in the operator's cab.

- Bucyrus-Erie 9W dragline

An older-model, diesel-powered dragline with available power of 110 volts AC, the Bucyrus-Erie 9W dragline will be equipped to evaluate different types of smoke detectors as an early fire warning system.

3.5 DESCRIPTION OF AUTOMATIC FIRE PROTECTION SYSTEMS

Five fire protection systems were developed for application on the various units of mine equipment. Technology employed in the performance of Bureau of Mines Contracts HO122053 and HO232059 was incorporated with the stated interests of mine operators in the redesign efforts. The resulting systems are described in the following paragraphs.

3.5.1 System I (see Figure 11)

System I is a cost-effective version of the previously developed system with thermal-wire and optical flame detectors, stored-pressure, dry-chemical-filled cylinders, logic control, and ambient temperature compensation. Two extinguisher cylinders are used to protect the engine, transmission or motor generator, and fuel/oil tanks. The extinguishant, an ABC-type dry chemical using solenoid valves for discharge, is nitrogen pressurized. A pressure switch monitors the nitrogen pressure.

The control panel assembly consists of an ON-OFF-TEST/RESET switch, audible and visual fire warning indicators, and a manual discharge button. The electronic control printed wiring assembly is inside the control box. The control panel switch is a three-position toggle switch. Down is OFF, midposition is ON, and momentary-up position is SYSTEM TEST AND RESET. The manual override discharge button initiates discharge of extinguishant even when the control panel power switch is off.

SYSTEM I — DUAL SENSOR, SEMIAUTOMATIC FIRE PROTECTION SYSTEM

System Major Components/Features

- Optical Sensing Element — Instant detection of flash fire in area protected; provides quicker response than thermal wire alone.
- Thermal Wire Sensing Element — High reliability; highly resistant to actuation by false stimuli.
- Thermistor Probe — Compensates for rapid changes in ambient temperature, improves system performance (cold weather environment only).
- Environmental Housings — Protect cylinders, valves from damage.
- Logic/Control Unit — Warns operator, both visually and audibly, of danger; utilizes output signals from both sensors to determine if flash fire or slower growing fire occurred; determines if system malfunction is present.
- Cylinder and Solenoid Valve Combined — Stores pressure and powder together, eliminating powder caking problems.
- Remote Discharge Switch — Allows manual discharge of system at ground level.

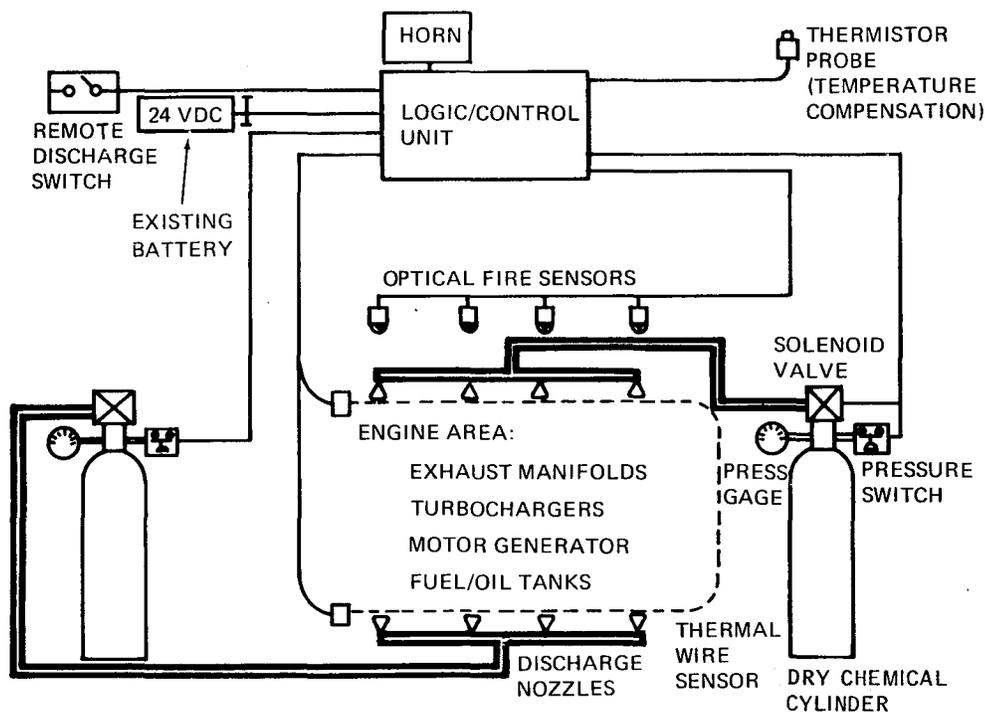


Figure 11 SYSTEM I MAJOR COMPONENTS

Normal system operation is initiated by the control panel ON-OFF switch or the truck master switch, provided the system ON-OFF switch is in the normal ON position and power is supplied through the truck master switch. During the first 3 seconds after initiation, electronic inputs to the thermal and optical detectors simulate a fire signal. All three indicator lights on the panel should illuminate during the integrity check. After 3 seconds, the system automatically returns to the green POWER ON condition if no malfunction is found in the system self-checking procedure.

If an optical flame sensor detects a fire, the yellow FAULT/FLAME warning light on the control panel illuminates and the audible alarm sounds. There is no automatic discharge of the dry-chemical powder for fires sensed only by the optical sensors. If only the thermal device senses a fire, the red FIRE warning illuminates and an audible alarm sounds. The system automatically discharges the agent after 10 seconds of delay, during which the driver may stop, turn off the engine, and test the system for malfunctions.

Moving the control panel switch to TEST/RESET during the 10-second delay will reset the discharge delay to provide an additional 10 seconds after the control panel switch is released from the test position.

When optical and thermal wire sensors detect a fire simultaneously, the dry-chemical powder is discharged immediately to suppress the probable flash fire situation. Immediate discharge may also be manually initiated by striking the discharge button. It is not necessary that the control panel be in the ON position because electrical power is supplied directly by the battery.

A remote system discharge switch, at the base of the ladder, permits manual actuation of the system without any fire signals, regardless of the position of the control panel switch or the truck's master switch.

3.5.2 System II (see Figure 12)

System II is designed to be essentially the same as System I, but without optical flame sensors and ambient temperature compensation. The normal alarm temperature is fixed at 260°F and does not decrease during low

SYSTEM II — SEMIAUTOMATIC FIRE PROTECTION SYSTEM

System Major Components/Features

- Thermal Wire Sensing Element — High reliability; highly resistant to actuation by false stimuli.
- Logic/Control Unit — Warns operator, both visually and audibly, of danger; utilizes output signals from sensor; determines if system malfunction is present.
- Environmental Housings — Protects cylinders and valves from damage.
- Cylinder and Solenoid Valve Combined — Stores pressure and powder together, eliminating powder caking problem.
- Remote Discharge Switch — Allows manual discharge of system at ground level.

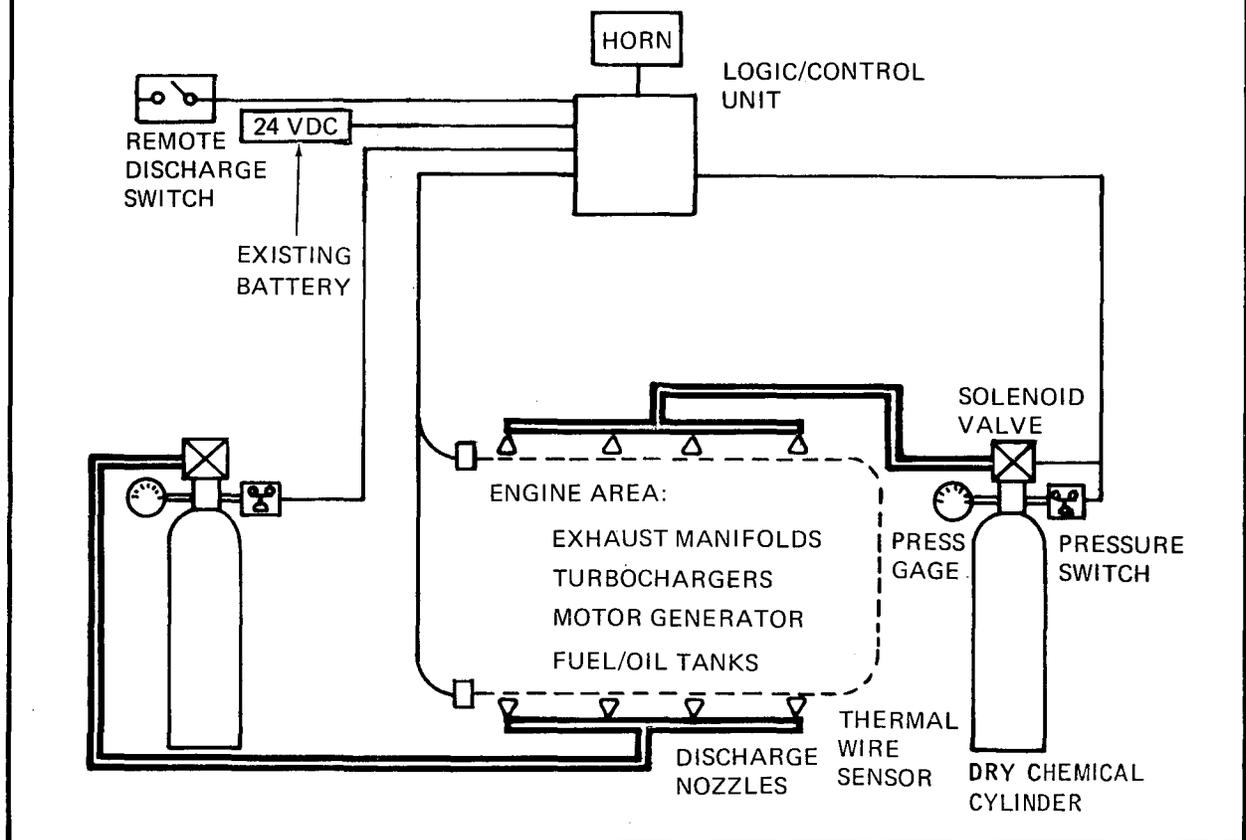


Figure 12 SYSTEM II MAJOR COMPONENTS

ambient temperatures as with System I. Normal operation procedures are identical to those for System I. Because optical sensors are eliminated from the system, however, the yellow indicator reads FAULT, rather than FAULT/FLAME. Additionally, System II always provides a 10-second delay for system check prior to automatic discharge.

3.5.3 System III (see Figure 13)

The problem of equipment operators being unable to activate manual fire protection systems during the panic of flash fire prompted the development of System III, a retrofittable system designed to automatically actuate a manual system. To obtain the desired automatic system discharge, point-type or line-type thermal sensors are used. The fire sensors electrically activate a newly designed solenoid valve which punctures a standard pressure cartridge (Ansul and Kidde).

Normal operation procedures are similar to those of Systems I and III. In this case, however, the FAULT signal will also indicate that the solenoid valve has been activated.

3.5.2 System IV (see Figure 14)

System IV is an alarm-only system that includes at least one sensor that provides both visual and audible alarms without discharging a fire extinguishing agent. Photoelectric smoke detectors are placed in the fire hazard areas of shovels and draglines. The System IV control panel is different from panels used in the other systems. Normal operation is to move the toggle switch to the ON position so that the green power light indicates the presence of 110 volts AC. The momentary test position allows testing of the two remaining indicators: the red fire warning light and the audible alarm. Visible smoke activating the smoke detectors will activate both the audible and visual alarms. Because heavy dust can activate the system, occasional cleaning of the detector photocell chamber is necessary.

3.5.5 System V (see Figure 15)

System V is a self-contained, battery-powered, automatic fire detection system that utilizes the new cartridge-puncture valve to activate existing

SYSTEM III — AUTOMATED MANUAL, CARTRIDGE/PRESSURE FIRE PROTECTION SYSTEM

System Major Components/Features

- Thermal Wire Sensor or Point Thermal Sensors — High reliability, highly resistant to actuation by false stimuli.
- Remote Discharge Switch — Allows manual discharge of system at ground level.
- Logic/Control Unit — Warns operator, both visually and audibly, of danger; utilizes output signals from sensor; determines if system malfunction is present.
- Solenoid Actuator — Discharges automatically and activates existing manual system.

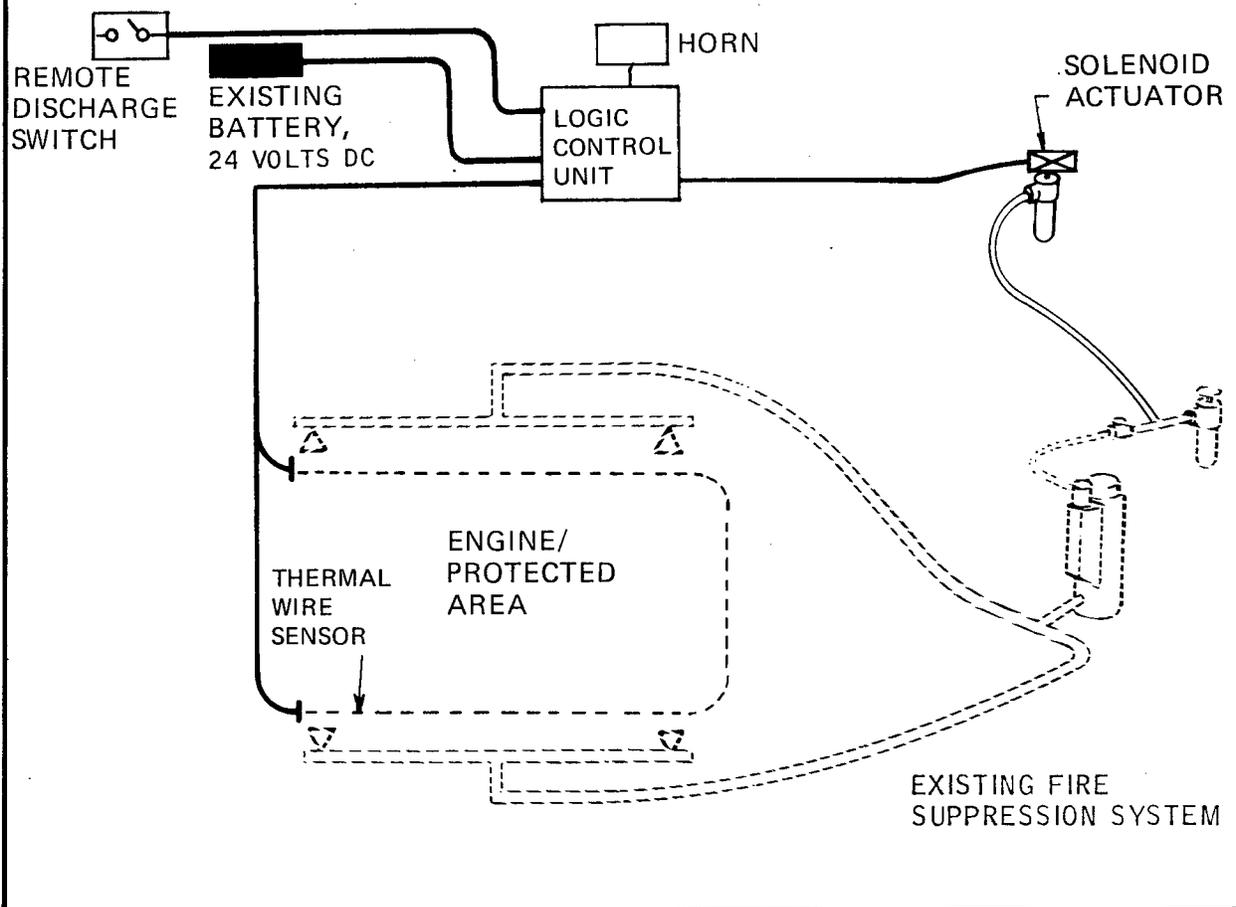


Figure 13 SYSTEM III MAJOR COMPONENTS

SYSTEM V — AUTOMATED MANUAL, CARTRIDGE/PRESSURE

FIRE PROTECTION SYSTEM

System Major Components/Features

- Thermal Detector — High reliability; highly resistant to actuation by false stimuli.
- Remote Discharge Switch — Allows manual discharge of system.
- Logic/Control Unit — Warns operator, both visually and audibly, of danger; utilizes output signals from sensors, determines if system malfunction is present.
- Solenoid Actuator — Discharges automatically and activates existing manual system.
- Self-Contained Battery.

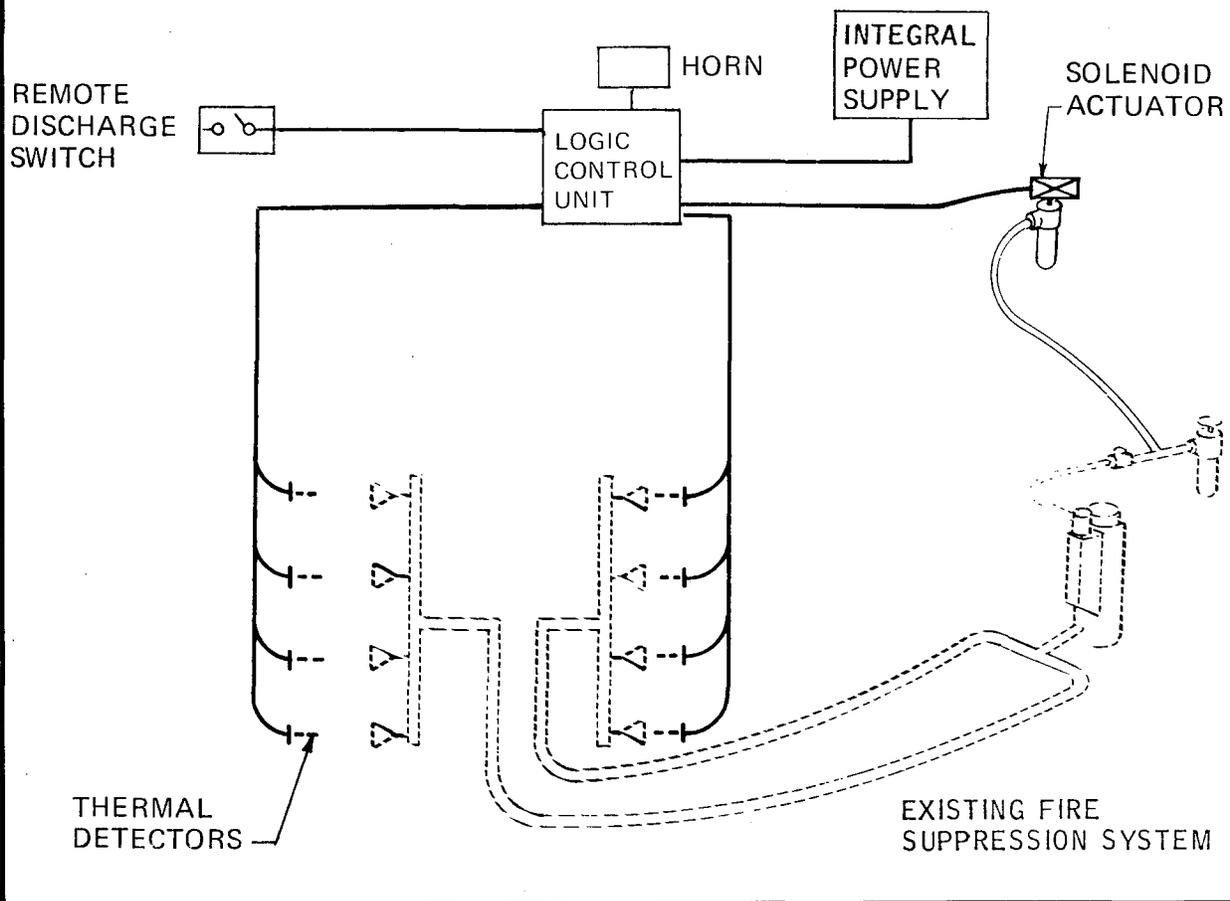


Figure 15 SYSTEM V MAJOR COMPONENTS

manual extinguishing systems. It is essentially identical in function and operation to System III, but uses a different power source. Different battery-charging methods may be necessary if recharging during preventive maintenance is not feasible.

3.6 SYSTEM COMPONENTS

The following paragraphs provide descriptions of technical design details of major components of the five fire suppression systems.

3.6.1 Control Panel Assemblies

Two similar control panel assemblies were fabricated for use with four of the five systems. One assembly (Part Number 5130257) is used with Systems I and II, in which optical flame detectors and stored-pressure containers with commercial solenoid valves are used. This panel is revised only slightly for System II. No optical flame detectors are used in System II, but the capability to use them is designed into the panel.

A second panel design (Part Number 5130399) is used with Systems III and V in which the newly designed cartridge-puncture solenoid valve is used. One solenoid output operates an external relay that activates the cartridge-puncture valve. The second panel does not allow use of optical sensors or the ambient temperature compensation feature.

Several vendor items were investigated prior to selection of a control panel housing that would be less expensive than that used in previous contracts. An off-the-shelf housing was sought which would provide the following features:

- Cost effectiveness
- Weather resistance
- Ruggedness
- Ready accessibility for servicing
- Availability.

A modularly constructed housing of 16-gage aluminum was tentatively selected. After assembling one housing, however, the unit was found deficient in the following areas:

- The metal gage was not sturdy enough for the mining environment.

- The housing construction made sealing against the environment difficult.
- Fasteners for assembly (#4 screws) were inadequate.

Openings were easily observed at all corners of the housing. Nominal weight applied on the top and bottom panels allowed unreasonable flexing, further widening the gaps and potentially causing fractures of the fixed printed-circuit board. The small, nonlocking assembly fasteners also would break easily or vibrate loose in the activity encountered in normal mining environments.

FMC then fabricated a housing that would overcome the deficiencies in the 16-gage unit. A simple, two-part box assembly was designed using 14-gage steel and #10 screws for assembly. The design allowed for reasonable sealing and easy servicing. Figure 16 depicts the housing assembly.

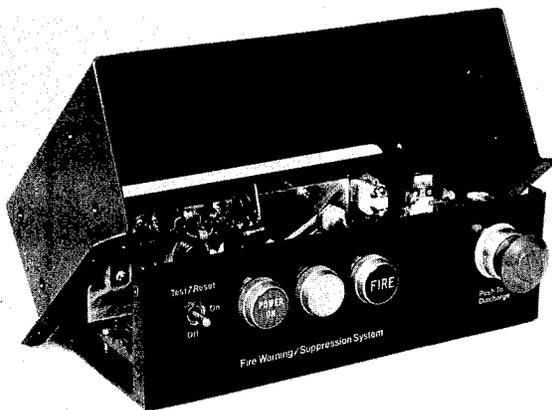


Figure 16 CONTROL PANEL ASSEMBLY (FMC Photo 66542)

Controls for the panel were selected for general ruggedness, visibility, price effectiveness, and straightforward operation. Standard automotive oiltight lights (DiaLight), 1 inch in diameter, were selected. A special lamp (General Electric Part Number C7A), reportedly more resistant to high levels of vibration and providing long service, was also obtained.

A large pushbutton industrial switch (Allen Bradley Part Number 800T-FX6A1) for manually discharging the extinguishing agent was used to provide high visibility and long life.

This switch is installed with a maintained-contact arrangement to allow it to lock into the discharge position without having to be held.

The pushbutton switch was further modified to accept a seal wire so that cursory inspection would indicate if it had been manually actuated.

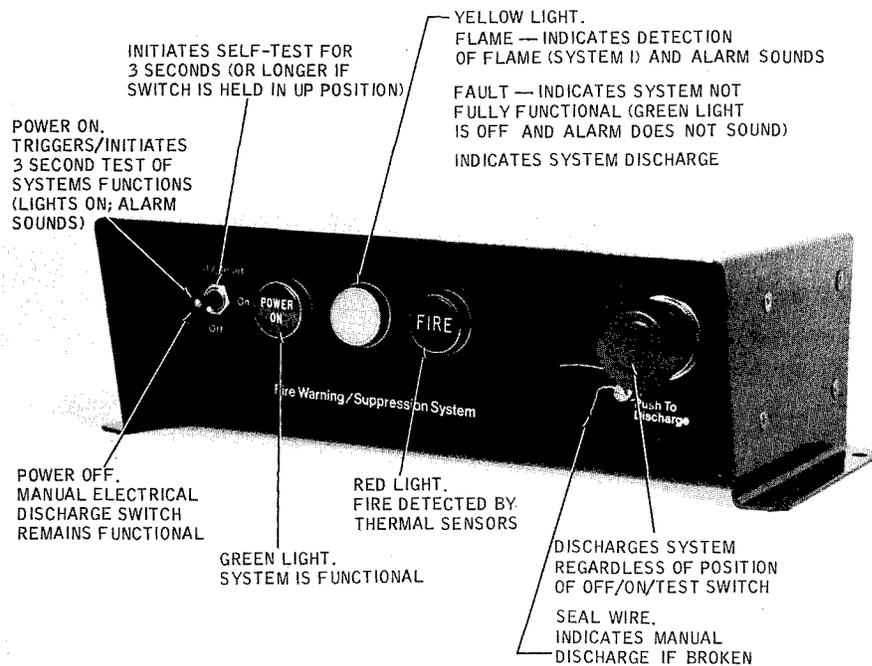
Letters on the front panel nameplate were embossed to maintain legibility through the service life of the system.

To allow easy access for maintenance and repair, all components are mounted to the bottom half of the housing section (Figure 16). The display components are on the front, and the cable connector, fuses, and audible alarm speaker extend from the rear. The printed-circuit card and power board assembly are housed within. An earlier design had located these items on the side; however, this arrangement caused tight and difficult assembly inside the housing.

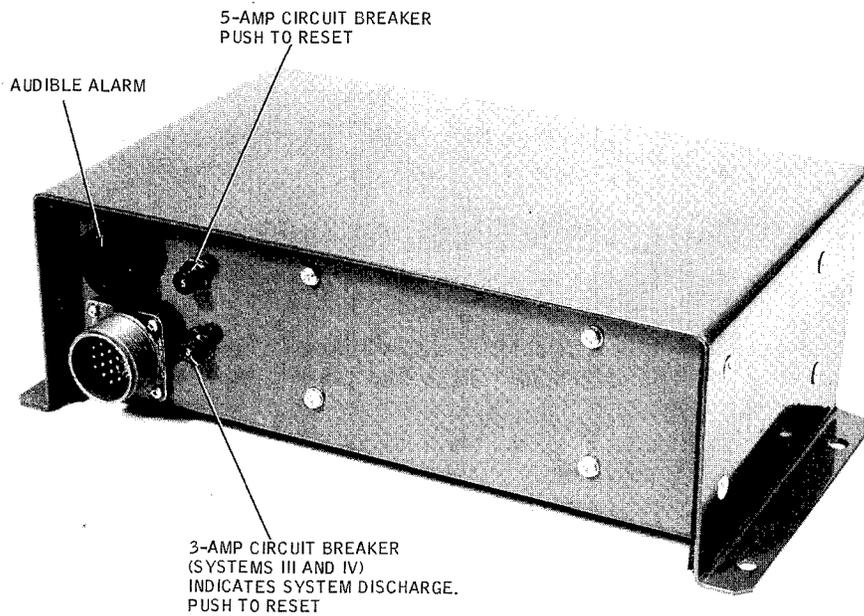
Figure 17 shows the panel display for Systems I, II, III, and V. The operator needs only two switches for system function, the OFF/ON/TEST switch and the red discharge button. When the system is turned on, a 3-second test of all functions follows. If the system is functional, the green POWER ON light will illuminate. If a malfunction exists, it will be indicated by the yellow FAULT light. At any time the operator may initiate a system check by moving the OFF/ON/TEST switch to the TEST/RESET position. The test will automatically continue for 3 seconds unless the switch is manually held in the TEST position. All lights and alarms are activated during a system check.

Besides indicating a system malfunction during a system check, on System I the yellow indicator is a FAULT/FLAME light, indicating detection of flames by the optical sensors but only if the green POWER light remains simultaneously. The system will not discharge automatically, however, unless the thermal detectors also indicate a fire. Fire detection by both the optical and the thermal sensors of System I causes an immediate system discharge.

Automatic system discharge in the other systems occurs 10 seconds after the red FIRE light indicates that the thermal sensors have detected a fire. Following discharge, the yellow FAULT light illuminates without the green POWER indicator and audible alarm.



Front Panel



Rear Panel

Figure 17 CONTROL PANEL DISPLAY, SYSTEMS I, II, III, AND V (FMC Photos 66538 and 66540)

In all systems, audible alarms are also activated whenever fire or flames are sensed. The operator may also manually discharge the fire suppression system by pushing the red button on the right side of the panel.

Short circuits in the power supply may cause the green POWER ON light to go off. After correcting the circuit, pushing the 5-ampere circuit breaker on the rear panel should reset the system.

On Systems III and V, a 3-ampere circuit breaker protects the intermittent-duty solenoid valve from damage resulting from continuous application of voltage. Voltage is applied to the solenoid by a power contactor in the junction box, and the solenoid ground breaker returns through this circuit breaker. After the valve has punctured the carbon dioxide or nitrogen cartridge, the circuit breaker opens. The yellow FAULT light, without a green POWER light, then indicates the open solenoid circuit.

The control panel assembly for System IV (Figure 18) consists of one alarm monitoring unit and as many as 10 remotely mounted smoke detectors. When any smoke detector senses smoke, a red FIRE indicator illuminates and an audible alarm sounds. The system requires 110-volt AC power for operation.

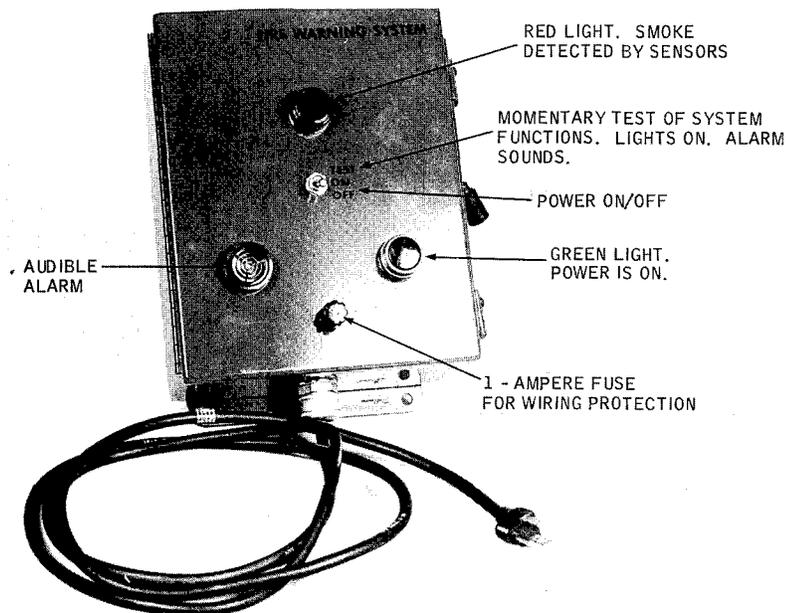


Figure 18 CONTROL PANEL DISPLAY, SYSTEM IV (FMC Photo 66533)

A front panel OFF/ON/TEST switch is provided to control system operation. A green POWER ON light indicates that the system is on and AC power is available. When the switch is held in the momentary TEST position, the red FIRE light illuminates and an audible alarm sounds, indicating that the monitoring unit is functioning and that wiring to the sensors is intact. The system should be tested frequently and should normally remain in the ON position. The OFF position is provided to disable the fire protection system after a smoke alarm has been noted or in the event of a sensor failure causing a continuous audible alarm.

Power is supplied to the smoke sensors from the monitoring unit. A 1-ampere fuse on the front of the unit protects the wiring. A blown fuse will disable the system and the POWER ON light will not light. An end-of-line power-monitoring relay is located near the detector farthest from the controls to detect both a break in the power wiring, which disables one or more detectors, and a break in the alarm contact wiring. Because the test switch connects through the power-monitoring relay, any wiring malfunction will be indicated at the panel by failure of the FIRE light to illuminate when tested.

The monitoring unit is housed in a red 12- by 10- by 4-inch oiltight JIC hinged-cover enclosure with 1/2-inch conduit openings for wiring to the remote detectors and the power source.

3.6.2 Fire Extinguisher Cylinders and Valve Assembly (see Rebuild Instructions, Appendix C)

After a difficult search and lengthy negotiation for an appropriate cylinder, the Pressed Steel Tank Company standard 20-pound carbon dioxide steel cylinder was made available for use in Systems I and II. The cylinder is used as supplied, except that leakage problems required replacing the 3/4 NGT threads with 1-1/16-12 threads with O-ring seat per MS33649-12. Figure 19 presents vendor-supplied construction details.

Cylinders are filled with 25 pounds of monammonium phosphate dry-chemical powder and pressurized to 500 psi with dry nitrogen. Pressurizing is accomplished by reversing the nitrogen flow through the solenoid valve

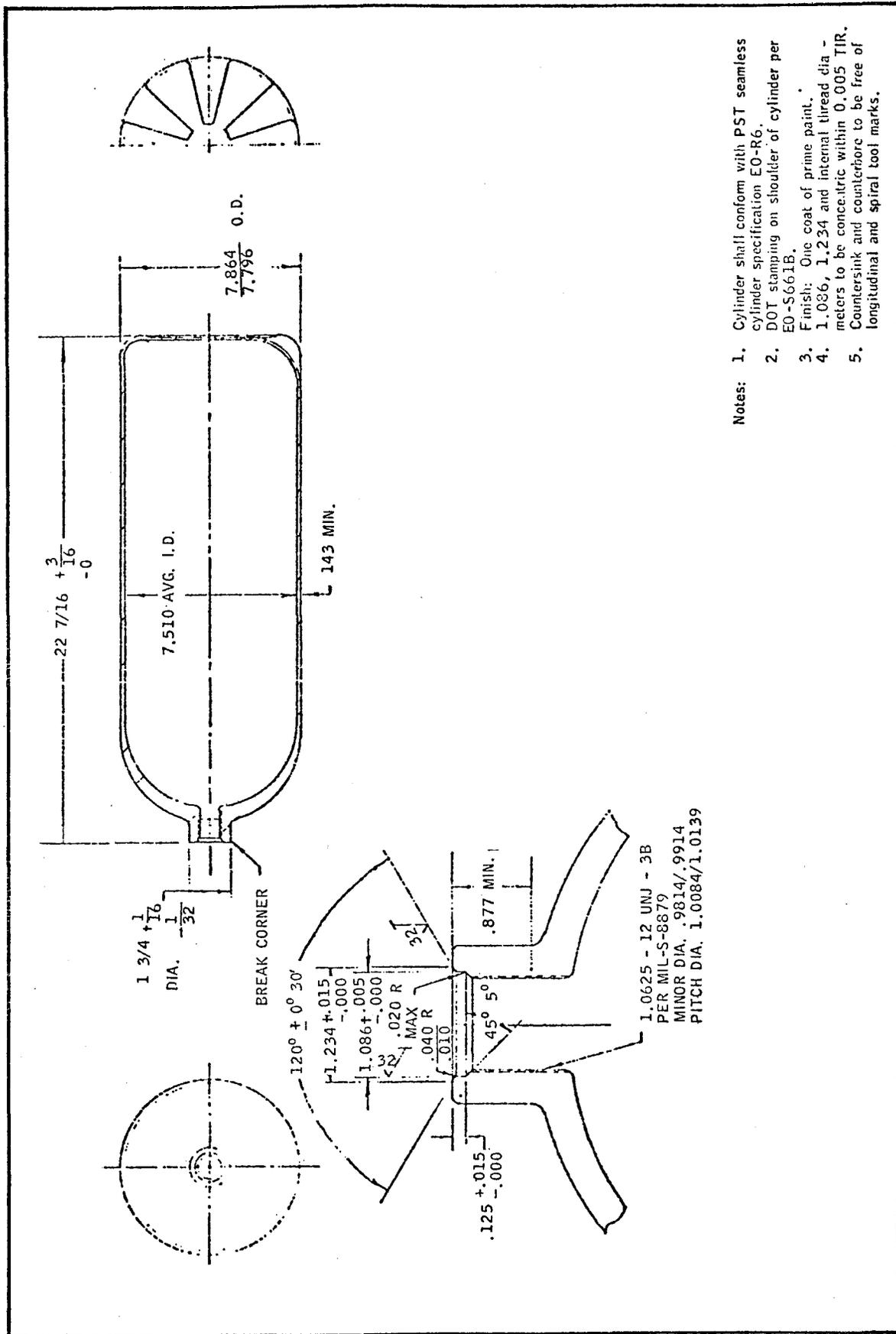


Figure 19 PRESSED STEEL TANK COMPANY CYLINDER, CONSTRUCTION DETAILS

exhaust and down the siphon tube assembly. When tested, 98 percent of the 25 pounds of powder was expelled in a 4-second period when no hoses or piping manifolds were attached.

Use of a high-pressure cylinder allows customer selection and use of any of the several available dry-powder chemical agents as well as any gaseous agents (e.g., carbon dioxide or Halon compounds). The cylinder is somewhat overdesigned for containing dry chemical at 500 psig, but its capability for containing CO₂, Halon 1301, and any dry chemicals and its relatively low cost encourage its usage. A two-way, normally closed, pilot-controlled solenoid valve (ASCO Part Number GS-HP-X8223B5) is used in conjunction with the high-pressure cylinders to allow automatic discharge of the extinguishing agent. A continuous-duty 24-volt coil (Part Number 24/DC TPL-9735), located on the valve, allows a signal from the control box to lift the pilot valve off the pilot seat that in turn opens the 3/4-orifice main valve and discharges the powder agent. The same valve is available with a manual lever for opening the pilot area (ASCO Part Number GS-HP-X8223B5-MO-24/DC TPL 9735).

Adaptation of the solenoid valve to the cylinder is accomplished through a siphon tube. The connection of the pipe thread located on the top of the siphon tube with the solenoid valve pipe threads has been a source of leakage problems at 500 psi, but effective use of Teflon tape has overcome the problem. Use of O-rings throughout would seemingly be the ideal solution; however, this would mean a modification of the valve thread that is now supplied as a standard catalog item by the manufacturer.

Additional small leaks past the main valve Teflon seal and the coarse valve body seat below the Teflon seal enlarge the leakage problem. Machining this seat from about 250 microinches to approximately 32 microinches and replacing the Teflon seal with a softer material was investigated. Each of four tests conducted using Neoprene seal material on 32-microinch finish has been successful in stopping the valve leakage. The ASCO valve supplier and ASCO engineers worked closely with FMC engineers to solve the leakage problem. After two design changes, a new cast-urethane seat was fabricated and has proven extremely effective during testing. The ASCO valve (Figure 20)

replaces another valve used in work under previous contracts. The ASCO simplicity of design and use of fewer parts should result in less maintenance. One large nut (end cap of Figure 20) replaces four capscrews on the previously used valve; the operational pressure ratings and continuous-duty solenoids also were not features of the previous Bureau of Mines system.

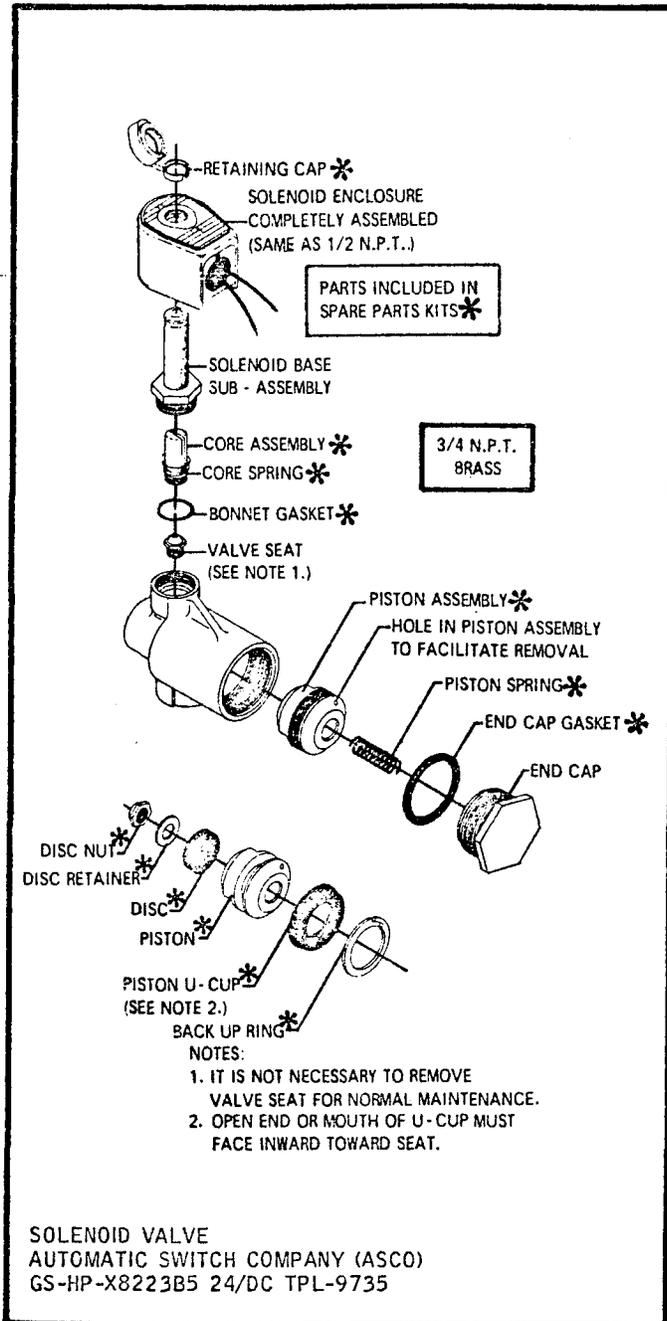


Figure 20 ASCO VALVE ASSEMBLY

3.6.3 Cartridge-Puncture Valve (Part Number 5130319)

For Systems III and V, a new valve was needed that would allow automation of existing manual fire suppression systems. As manufactured by Ansul and Kidde, such systems utilize a small pressurized cartridge that either expels the fire suppression agent directly or activates a second, larger cartridge that expels the powder chemical agent (Figure 21). The valve would function by rupturing the cartridge diaphragm.

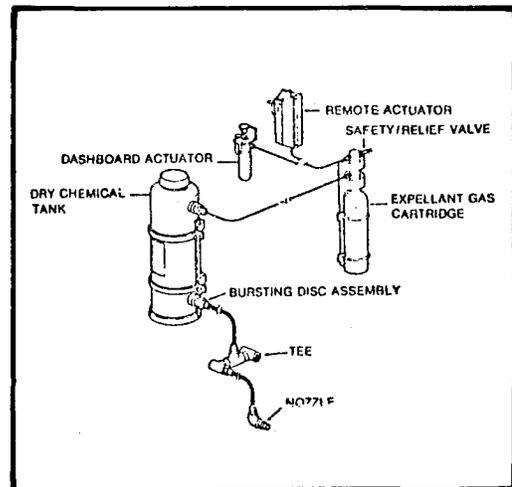


Figure 21 EXISTING MANUAL FIRE SUPPRESSION SYSTEM

The following criteria were established for the valve:

- Seal manufacturer should be same as cartridge manufacturer, for component compatibility.
- The cartridge must remain sealed until complete release is desired.
- Seal penetration forces must be adequate to puncture the manufacturer's seal (or that of another manufacturer, if one is substituted).
- Valve must be highly durable and reliable for use on mining equipment.
- Valve must be weatherproof.
- Temperature tolerance should be within -40°F to 125°F .
- Components should be available off the shelf.

Prior to initiating the design effort, a search was conducted to determine if the valve needed to accomplish the automation task was commercially available. None was located. An earlier FMC design concept (Figure 22) was then re-evaluated, and effort was directed toward establishing necessary requirements.

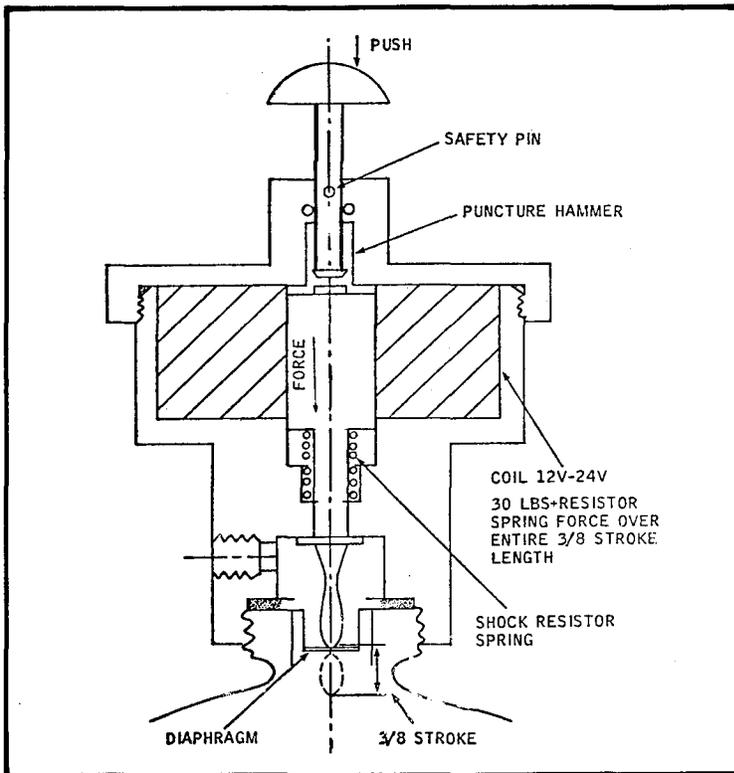


Figure 22 CARTRIDGE-PUNCTURE VALVE, INITIAL FMC CONCEPT

Several tests, as shown in Figure 23, were performed to determine the energy required to rupture the pressure-retaining diaphragm on the Ansul and Kidde cartridges. An Ansul manual actuator assembly was used to penetrate the cartridge.

Because higher-than-anticipated forces were encountered, the design being considered would require a larger solenoid. Shocks would also require a large retaining spring be used if the solenoid core were used to puncture the cartridge.

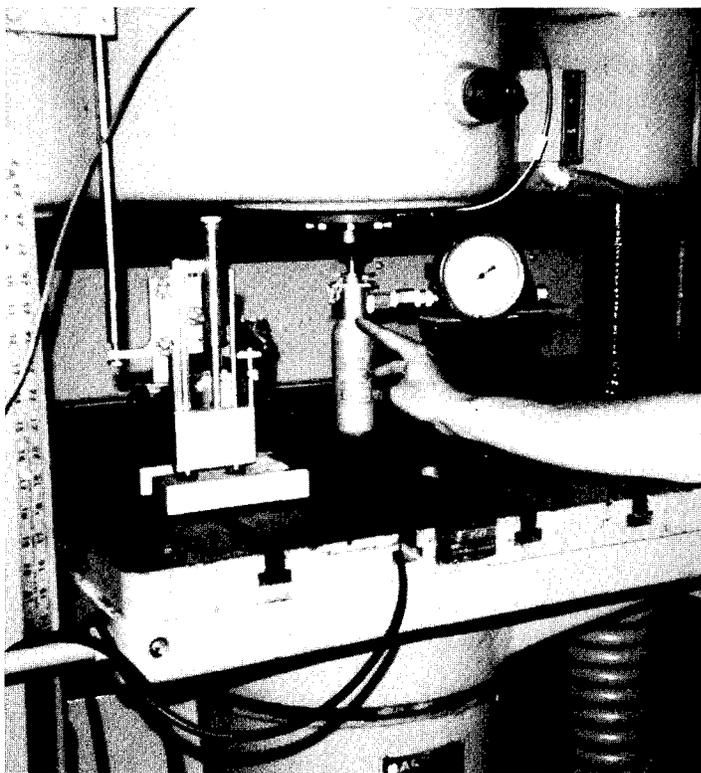


Figure 23 CARTRIDGE SEAL PENETRATION TESTS

The original concept was thus considered unfeasible. Complete test results and design considerations are documented in Appendix C.

Follow-up design efforts produced three valve variations. The first incorporated a spring-loaded puncture rod released by a smaller solenoid (see FMC Drawing 5130111, Appendix D). The valve design proved feasible, but not cost effective because approximately 15 purchased parts and 15 machined parts were required for the valve assembly.

A mockup of a second valve design (Drawing 5130226, Appendix D) was tested for the following features:

- Spring preload ability to repeatedly puncture cartridge seals
- Spring release mechanism ability to hold the drive penetration pin securely without excessive force and component wear
- Solenoid performance equal to vendor rating and proper solenoid alignment.

Although tests concluded that the requisites could be met (see Appendix C), it also was apparent that minor design changes would provide higher reliability and greater cost effectiveness.

A third design was, therefore, developed (FMC Drawing 5130319, Appendix D) to include the following features:

- Use of a solenoid with 22-gage (AWG) coil wire to yield greater release forces at lower voltages

- Use of casting for valve body and cap to reduce number of machined parts
- Insertion of plunger and spring from the top
- Elimination of roll pin retention of plunger spring
- Use of rib in cap to facilitate installation
- Use of bronze bearing in tripper guide to reduce friction.

The final design change resulted in the following improvements over the original concept:

- The number of purchased parts was reduced from fifteen to eight (including castings).
- The number of machined parts decreased from fifteen to three (including castings).
- Approximate unit costs (lots of six) were reduced from \$1,200 to \$400.

The final valve assembly (Part Number 5130320), to be used with Kidde cartridges, is essentially the same as that shown on FMC Drawing 5130319 (Appendix D) except the plunger was changed to provide an adapter for mounting to the cartridge. Figure 24 pictures a completed cartridge-puncture valve.

3.6.4 Sensors

The five types of sensors described in the following paragraphs are used on the various fire protection systems developed under this contract. Several are described in Appendix E.

3.6.4.1 Optical Flame Sensors (System I only)

Four Pyrotector Model 30-2013-9 sensors were used in engine compartments of equipment during

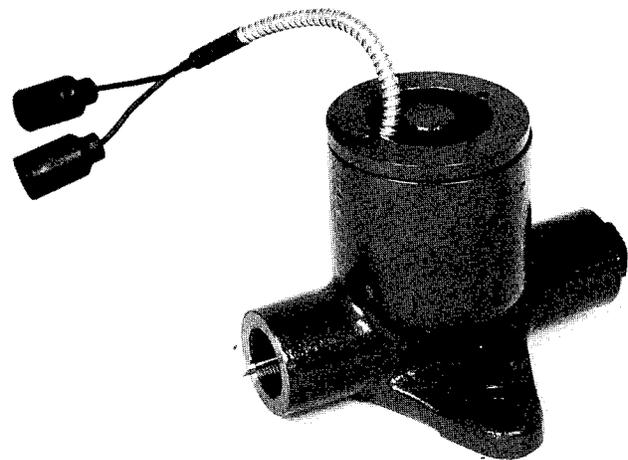


Figure 24 CARTRIDGE-PUNCTURE VALVE, FINAL DESIGN (FMC Photo 66530)

Bureau of Mines Contracts HO122053 and HO232059 with good results. They were incorporated into System I for this contract.

3.6.4.2 Thermal Line-Type Wire Sensor (Systems I, II, III, and V)

The Kidde thermal wire sensor (Part Number 896942) used for work under this contract is similar to those used in previous Bureau of Mines projects except that 16 feet was established as a universal length. Supplying standard lengths of the thermal wire will be more cost effective than supplying multiple lengths.

3.6.4.3 Thermal Point Sensors (Systems III and V)

Fenwal bimetallic switch-type heat sensors (Part Numbers 515309 and 515311), activated at 225°F and 325°F, are commonly available items offering both cost effectiveness and durability.

3.6.4.4 Ambient Temperature Compensation Sensors (System I)

A thermistor (Fenwal Part Number JB31J1) is mounted to allow relative comparison of ambient temperatures. The Kidde thermal wire alarm point (260°F) is automatically adjusted according to the ambient temperature to allow faster response during extremely low temperatures. For example, a negative 50°F ambient temperature adjusts the thermal wire sensor alarm point to 100°F.

3.6.4.5 Smoke Sensors (System IV)

Two models of Pyrotector smoke sensors (Models 30-52TC and 3040-RC-120) were used in the engine room of the Marion 8200 dragline. One of each model was evaluated for long-term performance. Both are photo-electric detectors that sense light scattered by smoke entering the detection chamber. Other sensors, such as the Becon Mark II (ionization) sensor from Anglo American Electronics or ENMET and Dynamation gas detectors (Taguchi gas sensing elements), have proven feasible in recent Bureau of Mines efforts (Contract HO262014, Mine Shaft Fire and Smoke Protection Systems) but were not viable candidates for this effort due to higher cost and their application.

The vehicles scheduled for smoke sensor installation were shovels and draglines on which considerable ventilation, dust, and motor arcing occurs. On one older dragline, a diesel-powered motor-generator was the primary power source. Ionization detectors are more sensitive in these areas and have reportedly caused a number of false alarms. Therefore, visible-smoke (i.e., photoelectric) detectors were chosen for use in System IV. Although heavy dust conditions are known to occur around draglines and shovels and could cause false alarms with either photoelectric or ionization sensors, the dust was not considered as detrimental an influence as the effect of high ventilation and motor arcing on ionization sensors.

Previous FMC/Bureau of Mines work with smoke detectors permitted evaluation of a variety of visible-smoke sensors. Although most units sold now incorporate light-emitting diodes (LEDs) as the light source (providing 40-year rated life), Pyrotector was one of the first suppliers to offer the LED sensors in a variety of models. The units also are relatively inexpensive, and Model 3040RC includes a smoke-rate-compensation feature not found in other units.

Model 30-52TC is a single-station, residential unit with LED indicators and test switches. Both models are powered by 110 volts AC and can be interconnected to provide alarms and continuity tests.

Vendor-supplied data sheets and other detailed information, on several sensors selected for this contract, are included in Appendix E.

3.6.5 Molded Cables

Sample cables are shown in Figure 25. Specially molded cables are used in Systems I, II, III, and V in connections to ambient thermistors and optical sensors and to interconnect the main control panel to a remote junction box. The cables provide improved reliability in harsh mine environments, a definite requirement determined from problems encountered in previous Bureau of Mines contracts.



Figure 25 MOLDED CABLES (FMC Photo 66526)

Connectors used on the cables are the same as those used by the military and have demonstrated ruggedness and durability in previous installations. A specially molded housing is fixed over the connector to provide a waterproof enclosure and resistance to environmental corrosion.

The optical sensor cables and the main cable connecting the junction box and control panel are shielded to alleviate problems with electromagnetic interference. The molded cables are supplied by Cam-Loc, a Division of Empire Products.

Other cables used to interconnect the various components are 16-gage, heavy-duty, flexible, and waterproof. Thermal insulation and/or flexible armor conduit was used in high-hazard areas.

3.7 FACTORY TEST DEMONSTRATIONS

The scheduled bench test demonstrations of developed hardware were conducted in December 1976, 6 months after start of contract work.

Three test arrangements provided 12 static and two discharge demonstrations of the developed systems. Figures 26 through 28 show the three test arrangements. The test agenda is described in Appendix F.

Test Plan A demonstrated both System I, using optical flame sensors and thermal wire, and System II with thermal wire only. Instant discharge occurred when both optical and thermal sensors were in alarm.

Test Plan B demonstrated Systems III and V using point-type thermal sensors.

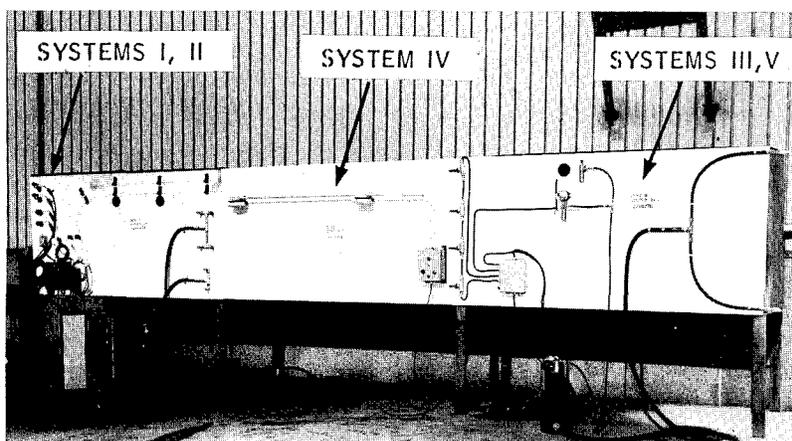


Figure 26 FACTORY TEST DEMONSTRATION SETUP, ALL SYSTEMS (FMC Photo 66253)

Discharge occurred after the 10-second delay period. Static tests demonstrated manual discharge capabilities during both Plan A and Plan B.

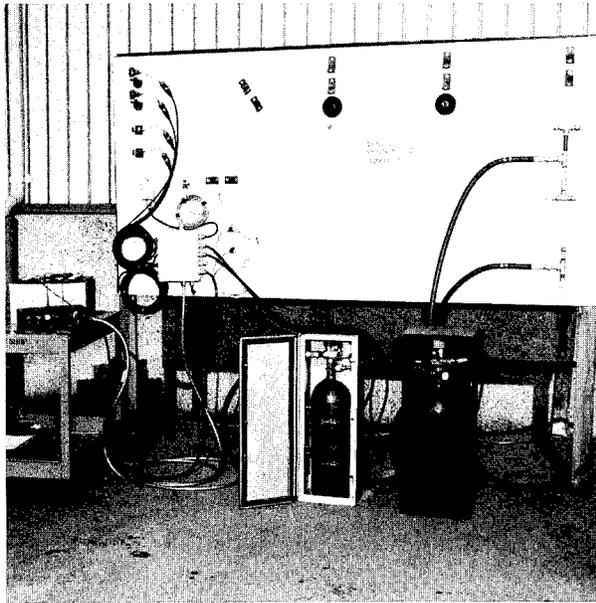
Test Plan C demonstrated System IV utilizing the photoelectric smoke detectors.

3.8 PHASE II, INSTALLATION, MONITORING, AND DEMONSTRATION

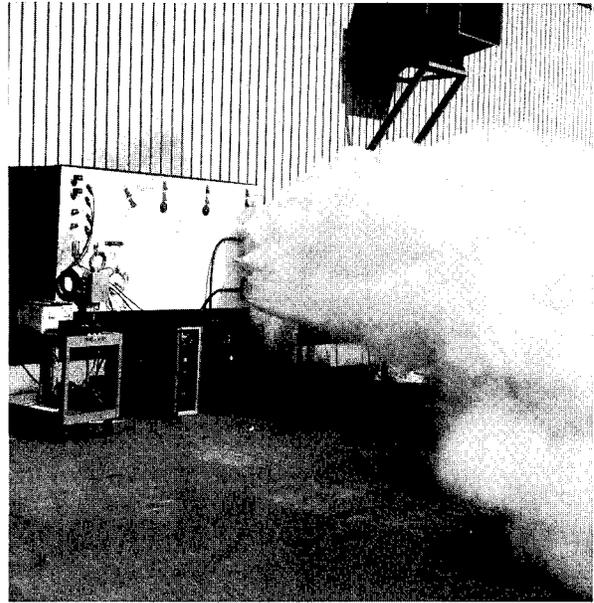
The following major tasks were scheduled for performance during Phase II:

- Install four fire protection systems in each of three mines.
- Monitor the system performance for 12 months.
- Conduct final demonstration tests of all systems at each mine.
- Prepare a final report to record all activities during the contract.

A contract modification revised the above scope of work by deleting installation and tests at one of the three mines. The duration of the tests was also amended so that monitoring of system installations lasted 10 months at one mine and 11 months at the other mine. The additional hardware, originally scheduled for use at the third mine, was used to replace failed or damaged units at the two mines.

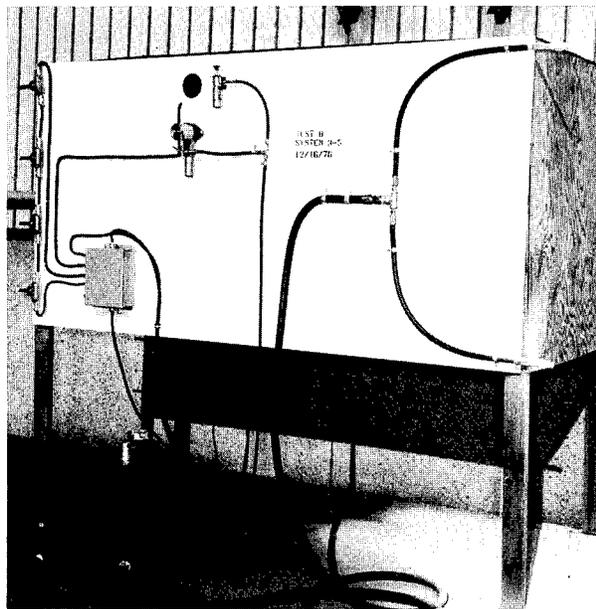


Test Plan A Demonstration Setup

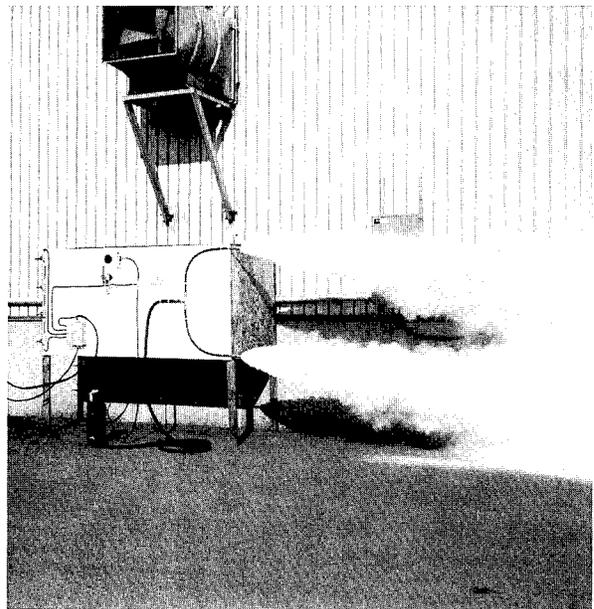


System Discharge

Figure 27 FACTORY TEST, SYSTEMS I AND II
(FMC Photos 66256 and 66257)



Test Plan B Demonstration Setup



System Discharge

Figure 28 FACTORY TEST, SYSTEMS III AND V
(FMC Photos 66260 and 66259)

Initial Phase II efforts completed tasks begun during Phase I. Negotiations with Diamond Crystal mine, one of the original and most concerned mines in the program, proceeded well from contacts made during 1975 when the extended test program was proposed. All approvals and necessary insurance certificates were received on 13 December 1976, and installation of the fire protection systems on Diamond Crystal equipment began on schedule, 10 January 1977.

The Jim Bridger coal mine was one of four mines contacted early in Phase I of the program. Management there offered the variety of mobile mine equipment and the labor assistance necessary to install and monitor the automatic fire protection systems. Verbal approvals were received after telephone contacts and an August 1976 followup visit when the selected equipment was reviewed. The draft agreement was routed and approved with necessary insurance certificates, so that all legal paperwork was in order 9 February 1977.

Technical difficulties experienced late in the Phase I effort involved the design, delivery, fabrication, and testing of hardware. The following unanticipated events resulted in a shortage of complete hardware systems available for immediate installation on equipment units following the Phase I factory demonstration on 16 December 1976:

- A manufacturer of integrated circuits changed the component circuit without changing the part number. The item, previously selected during Contract HO232059, was reordered and installed on all control panels under the current contract, but it did not function as intended.
- During an inspection trip to one of the mines, a candidate equipment item was checked, and its model number and serial number were recorded. Citing this data, manuals were ordered from the manufacturer. In accordance with the manual, the automatic fire protection system was designed for 24 volts DC negative ground. When installation was complete, it was discovered that the unit of equipment actually had a positive ground.
- Correction of pressure leaks in the vendor-supplied valves resulted in added activity to resolve the problem before installation could start.

- In the initial delivery of molded cables, the conductors were wired to the connector pins in error. These cables were returned and corrected by the supplier.
- Redesign of the control panel occurred midway through Phase I. The apparent cost-effective, off-the-shelf, modular control panel did not meet the criteria for ruggedness.
- Adaptation of a new cartridge-puncture valve required unanticipated design equal or superior to the more costly machining and welding configuration.

Following resolution of the Phase I difficulties, four fire protection systems were installed on mobile mining equipment at each of two operating mines: Diamond Crystal salt mine in Louisiana and the Jim Bridger coal mine in Wyoming.

Seven of the eight systems installed include fire suppression as well as fire sensing. Of the seven, two systems utilize stored-pressure dry-chemical containers, and five systems are connected to existing manually actuated (cartridge) systems. All systems are equipped with fire control panels to allow testing of the system and audible/visual fire alarms.

3.8.1 Installation of the Automatic Fire Protection Systems, Diamond Crystal Salt Mine

The Diamond Crystal mine is a large underground salt mine on Jefferson Island near New Iberia, Louisiana. Located in the northernmost group of islands, said to contain the purest salt of the bed, the mine has a 30-foot-diameter main shaft descending to 1,300 feet where offices and shops are located and mining operations are closely monitored. The salt is mined by the room and pillar method down to 1,700 feet using conventional mining techniques. The rooms are approximately 120 feet wide and pillars are 100 by 70 feet. Mobile mine equipment at the mine includes the following units:

- Two Euclid R30 trucks
- Two Euclid R35 trucks
- Two Caterpillar 988 loaders
- One Euclid 3-yard loader

- Three Goodman 2500 undercutters
- Two loading rigs
- Two Galion 125A cranes.

Each vehicle is equipped with an Ansul manually actuated, fixed fire suppression system. Mine management requested that automatic sensing systems be added to the systems. The mine had sustained a complete loss of a vehicle during a fire with only the manually actuated systems aboard. The manual system was not activated early enough to stop the fire. During this contract, four vehicles were equipped with automatic sensing systems installed and connected to the fixed suppression systems to provide automatic discharge of dry-chemical agent. The vehicles were monitored for 11 months and discharge demonstrations concluded the program.

The automatic fire sensing systems were installed during the week of 10 January 1977 on one Euclid R35 truck, one Galion 125A crane, one Goodman 2500 electric undercutter, and one Caterpillar 988 loader. Mine management elected to have the electrical power bypass the master switches on all vehicles so that the fire suppression systems would be active at all times.

3.8.1.1 Euclid R35 Truck (Figures 29 and 30)

The automatic system selected for the Euclid R35 truck was System III, which is described in Section 3.5.3 and shown in Figure 13.

Installation of System III on the vehicle is depicted in Figure 31. Installation involved the following:

- Protecting the heat-sensing wire from physical damage
- Connecting for electrical power
- Mounting the control panel, junction box, and valve.

After installing all components, it was learned that the vehicle electrical system ground was positive and the system was not compatible with the negative-ground automatic fire sensing system. No explanation existed, because the vehicle maintenance manuals and drawings indicated the vehicle was designed for negative ground.



Figure 29 EUCLID TRUCK
(Heat-Sensing Wire
Under Engine Hood)



Figure 30 MECHANIC INSTALLING
FIRE CONTROL PANEL
(Note System Junction Box
Lower Center)

Four alternatives were considered in the effort to make the fire sensing and suppression system operational:

- Change the vehicle to negative ground.
- Add 24-volt batteries and an alternator to provide a 24-volt DC negative-ground system separate from the vehicle positive system.
- Modify the control panel to operate ungrounded and change the grounded heat-sensing wire sensor to isolated point-thermal sensors.
- Modify the control panel circuitry to work on positive-ground system.

During a May followup visit by FMC personnel, the two ammeter wires and the two battery cables were reversed, resulting in a functional negative-ground electrical system and a compatible automatic fire protection system. The other alternative actions were eliminated because of the additional labor and the unique parts that would have been required.

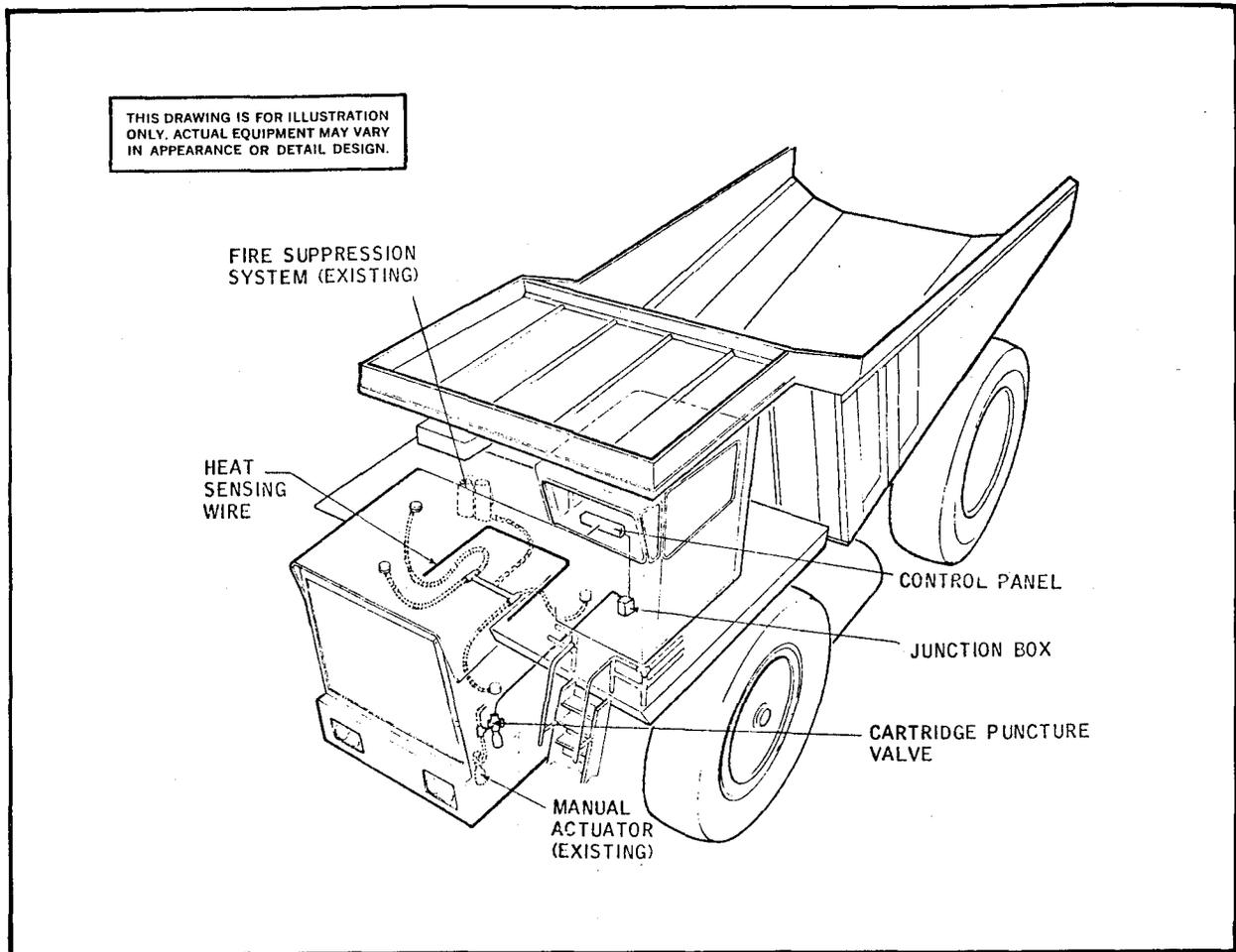


Figure 31 ARTIST'S CONCEPT, SYSTEM III INSTALLATION ON EUCLID R35 TRUCK

The 16-foot-long heat-sensing wire mounted under the engine cover (similar to Figure 35) was protected from physical damage by welding 1-1/2- by 1-1/2-inch angle guards to the cover near the wire. Electrical disconnects also were installed on each end of the looped sensing wire to allow complete removal of the hood from the vehicle for ease of maintenance tasks.

Electrical power connections were direct to the battery cable terminals after a supply of appropriate, uncorroded terminal strips could not be located elsewhere. New clamps were installed on the cables and the positive side was fused with a 30-ampere, in-line automotive fuse and fuse holder. These relatively unprotected and weak electrical power connections later proved a major source of problems.

The control panel was welded to 2- by 2-inch angles which were then welded to the operator's cab. This welding also proved a problem because warping of the 14-gage control panel cover later opened the housing seal, permitting salt dust and moisture (from steam cleaning) to enter the circuit.

The junction box (J-box) was mounted under the vehicle instrument panel, and the cartridge puncture solenoid valve mounted on the vehicle instrument panel along with the Ansul chemical containers. Silicone seal was eventually used around all seal joints of the control panel and J-box to assure integrity of internal components.

3.8.1.2 Galion 125A Crane (Figures 32 through 36)

Automatic fire sensing System V was selected for the mobile crane. This system is described in Subsection 3.5.5 and is shown in Figure 15. System V is essentially identical to System III, but with an integral electrical power supply. The power supply was necessary on the 12-volt crane to make it compatible with the inherent 24-volt DC fire protection system voltage.

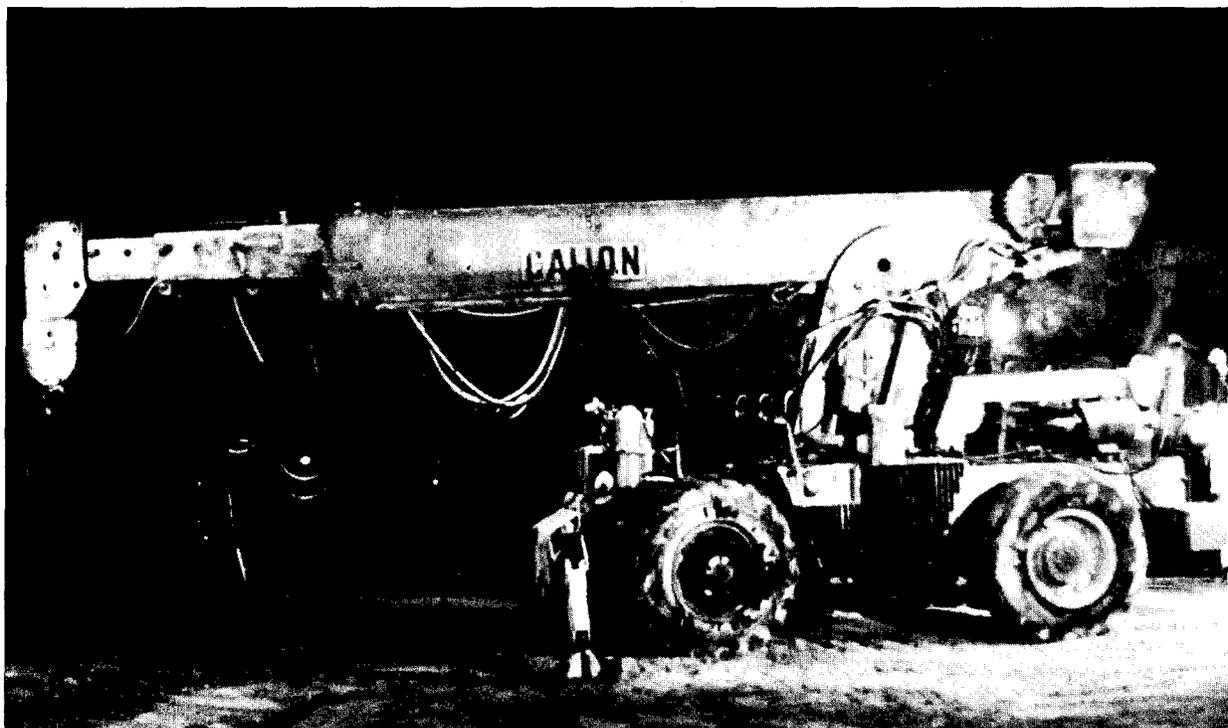


Figure 32 GALION CRANE

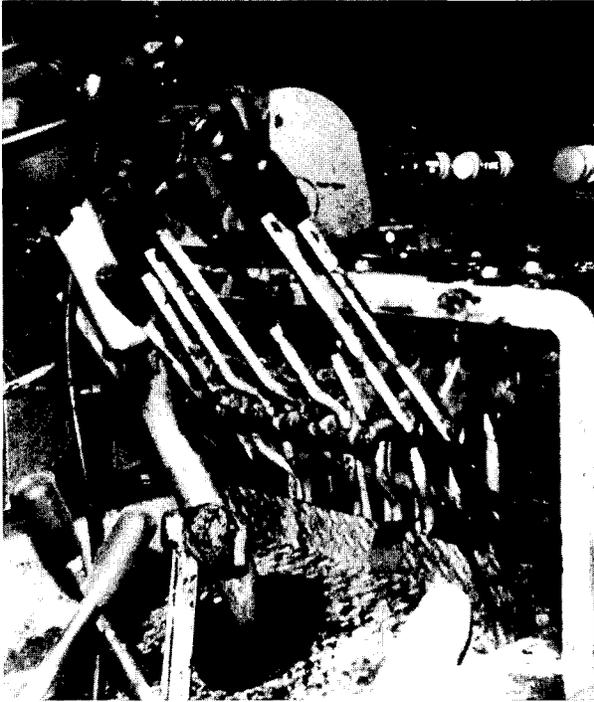


Figure 33 FIRE CONTROL PANEL
INSTALLATION ON CRANE

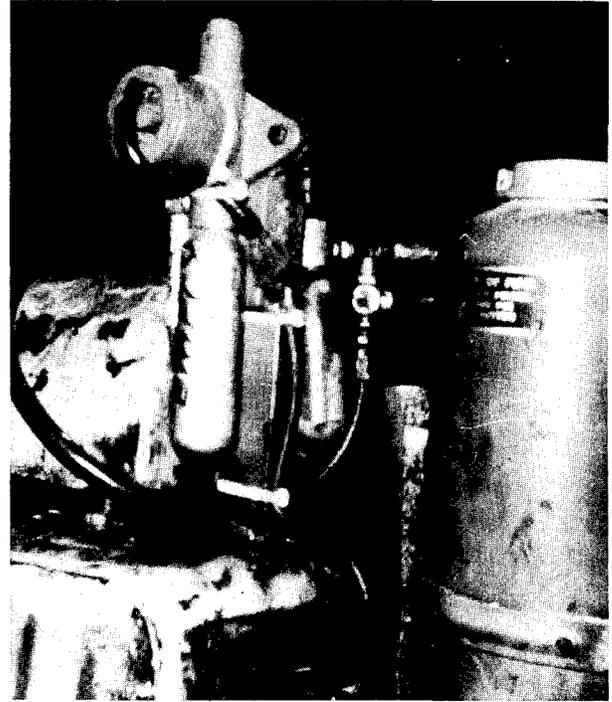


Figure 34 CARTRIDGE-PUNCTURE
SOLENOID VALVE
ON CRANE



Figure 35 ELECTRICIAN INSTALLING
HEAT-SENSING WIRE
UNDER ENGINE COVER



Figure 36 ALTERNATOR/REGULATOR,
24 VOLTS DC, INSTALLED
ON CRANE

Figure 37 depicts the installation of System V on a Galion 125A crane.

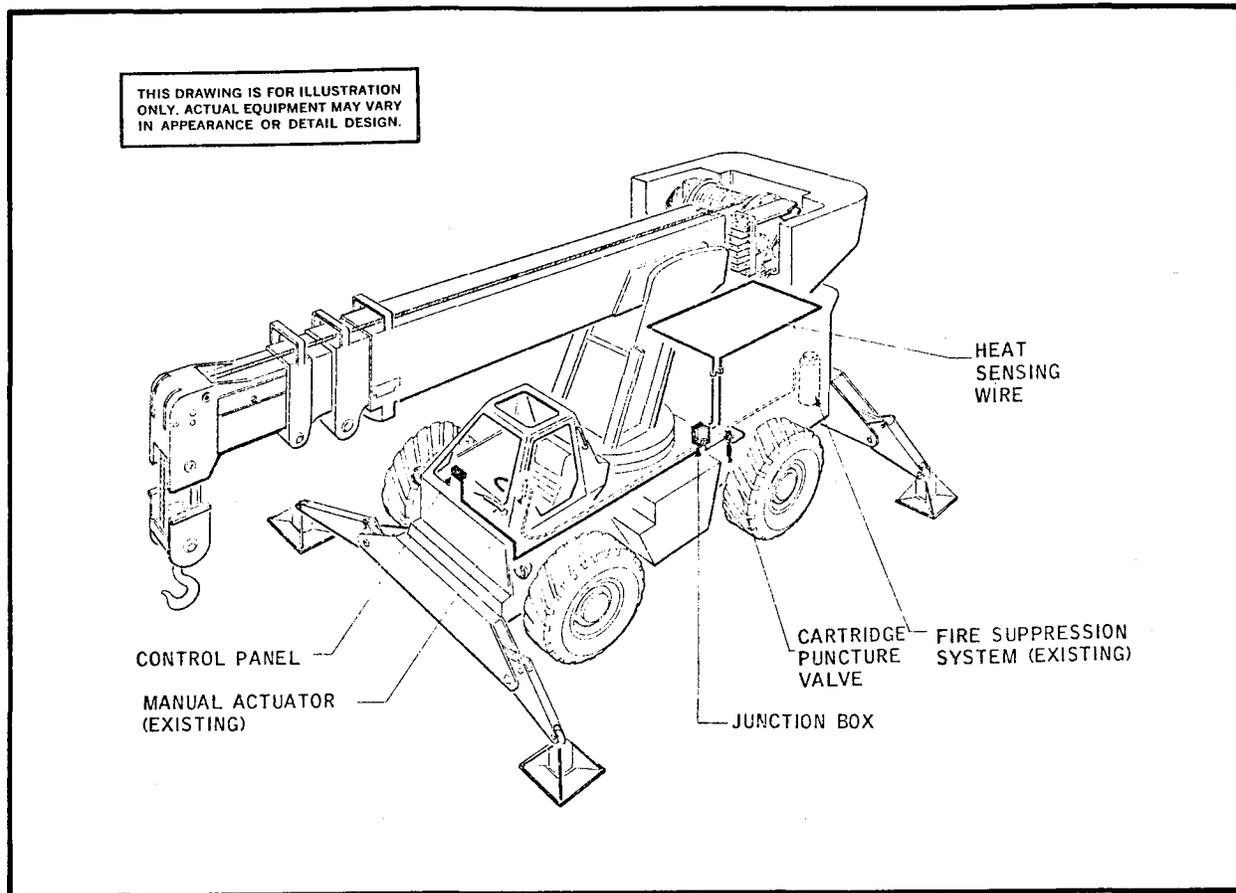


Figure 37 ARTIST'S CONCEPT, SYSTEM V INSTALLATION ON GALION 125A CRANE

To reduce the necessity for periodic recharging and maintenance of the isolated batteries, a separate alternator/regulator was installed.

A Brushless alternator, Niehofe Model A32-6, operating with 24/32 volts and 30 amperes, and incorporating an integral silicon transistor regulator, was purchased locally for this purpose. A new pulley and additional belt were assembled to a special bracket and mounted on the side of the engine. Originally, two 32-ampere-hour Delco 349 batteries (\$24 each) were furnished. Subsequently, the larger, maintenance-free, MF batteries without filler caps were used.

The series-connected, isolated batteries were placed in a protective metal box, and separate 30-ampere in-line fuses were used on the wires to the alternator. Cost for the alternator, pulley, and belt totaled \$123. The installation has eliminated all need to recharge the power supply.

An alternate approach for eliminating recharging the batteries was suggested but was not adopted because of higher costs, lack of component availability, and mine environment. This approach considered adding a 12-volt DC to 110-volt AC inverter which in turn would power a 24-volt DC battery charger.

Heat-sensing wire was selected for the installation (in lieu of point sensors shown in Figure 15) because of the similarity of the engine cover mounting to that on the truck. Use of the wire would also maintain a balance of sensors at the mine; i. e., two vehicles would utilize the heat-sensing wire and two would utilize individual point sensors.

Physical protection for the heat-sensing wire was again in the form of 1-1/2- by 1-1/2-inch angles welded to the hood. Rather than using disconnect plugs to ease removal of the hood, extra wire was coiled and secured to the vehicle.

The control panel was bolted (not welded) near the operator on 2- by 2-inch angle brackets welded to the vehicle. No warping of the panel occurred from the bolted installation.

The junction box was located near the oil reservoir on the right side of the vehicle, and the cartridge-puncture valve was placed on the same mounting post as the manual actuator for the Ansul fixed fire suppression system.

3.8.1.3 Goodman 2500 Cutter (Figures 38 through 43)

The presence of an AC trailing cable on the cutter vehicle made it necessary to also install System V on the Goodman 2500 cutter. The installation is

depicted in Figure 44. The isolated batteries on this vehicle again were the small Delco 349 units, rated at 32 ampere-hours. As with the crane, the larger MF-type batteries were later installed.

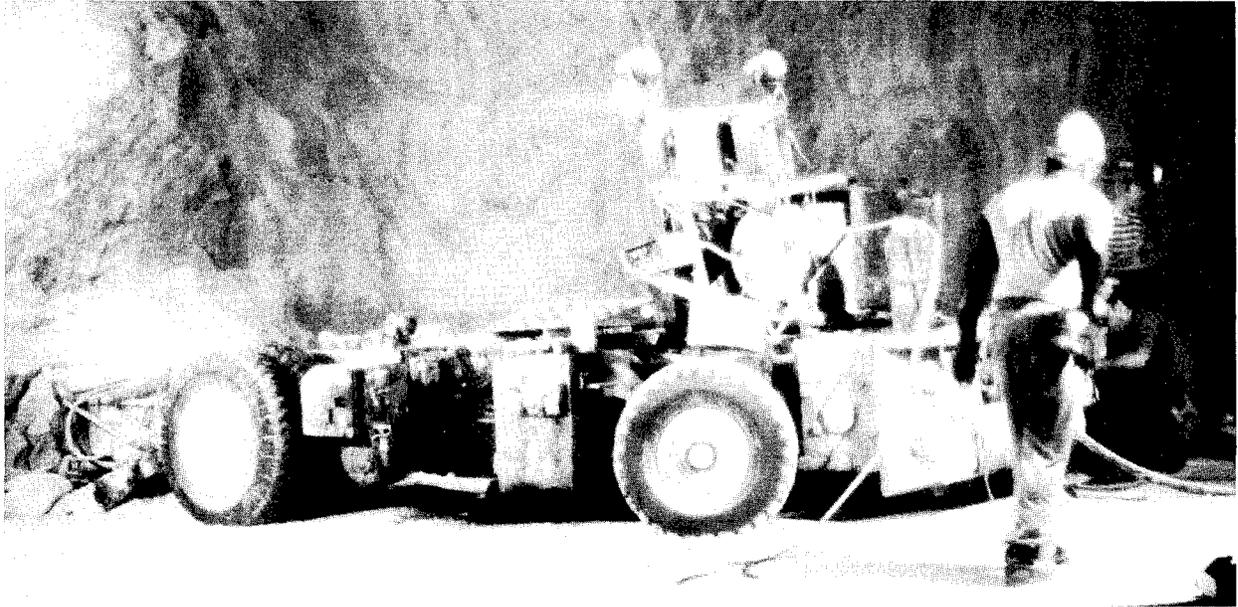


Figure 38 GOODMAN 2500 CUTTER

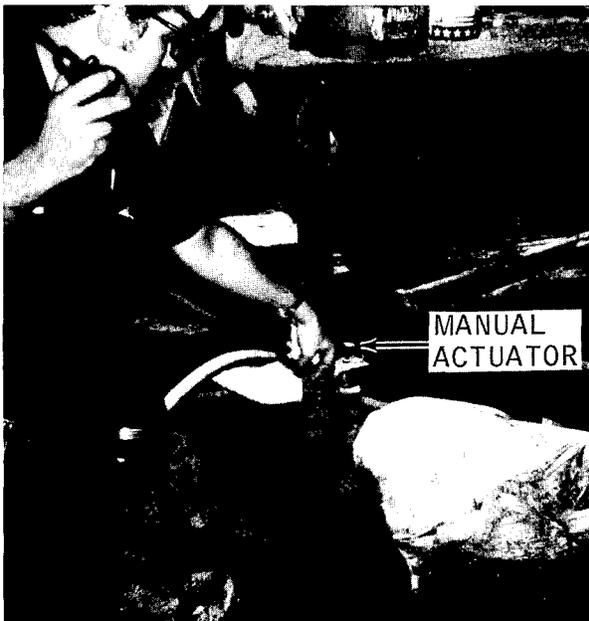


Figure 39 EXISTING FIRE SUPPRESSION SYSTEM ON CUTTER VEHICLE

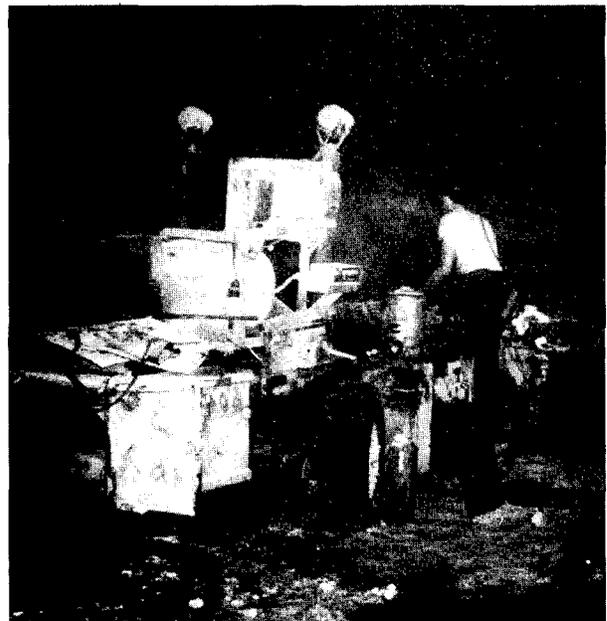


Figure 40 GOODMAN ELECTRIC CUTTER

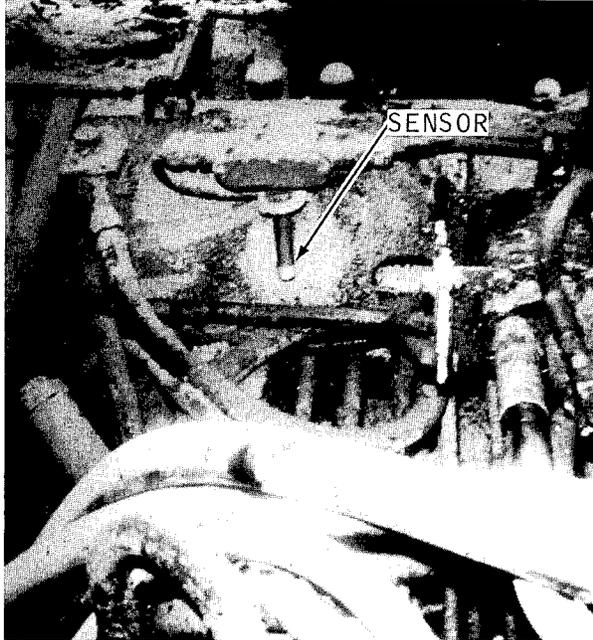


Figure 41 HEAT SENSOR
IN HYDRAULIC HOSE
AREA

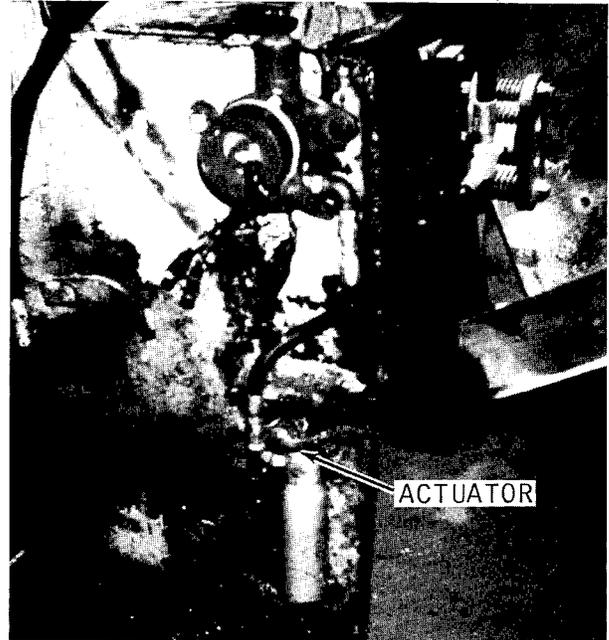


Figure 42 CARTRIDGE-PUNCTURE
SOLENOID VALVE
ON CUTTER (Note Manual
Actuator Below Valve)

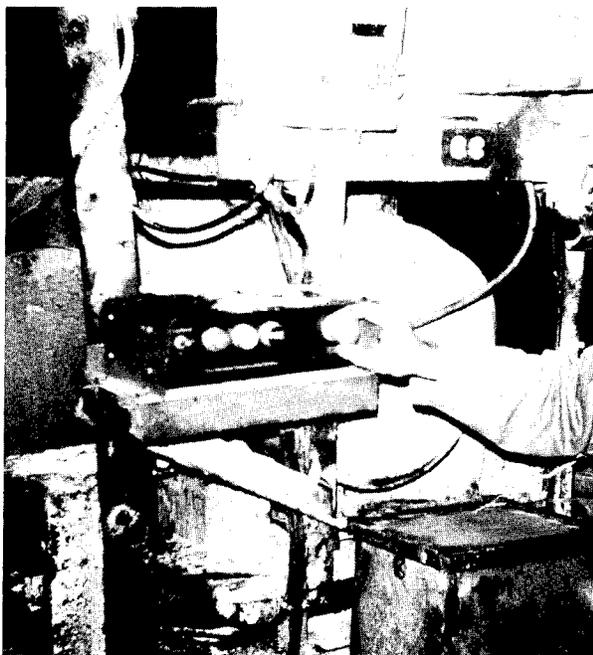


Figure 43 CONTROL PANEL ON
CUTTER (Note System
Battery Box Lower Right)

The 110-volt AC power available on the cutter powered a 24-volt DC, 5-ampere power supply that maintains a trickle charge on the two 12-volt, series-connected batteries that operate the fire protection system. This power supply alone was incapable of powering the 20-ampere solenoid load of the cartridge-puncture valve. A 30-ampere fuse in the battery box was used to protect the battery power wire against short circuits.

The smaller Delco 349 batteries were estimated as capable of powering the automatic fire

protection Systems III and V for 5 days (i.e., standby approximately 0.2 ampere) and Systems I and II for 2-1/2 days (i.e., 0.4-ampere load) depending on the amount of usage of the system. Longer-than-anticipated vehicle downtime and extra testing of the fire systems prompted mine personnel to install the larger automotive-type MF batteries.

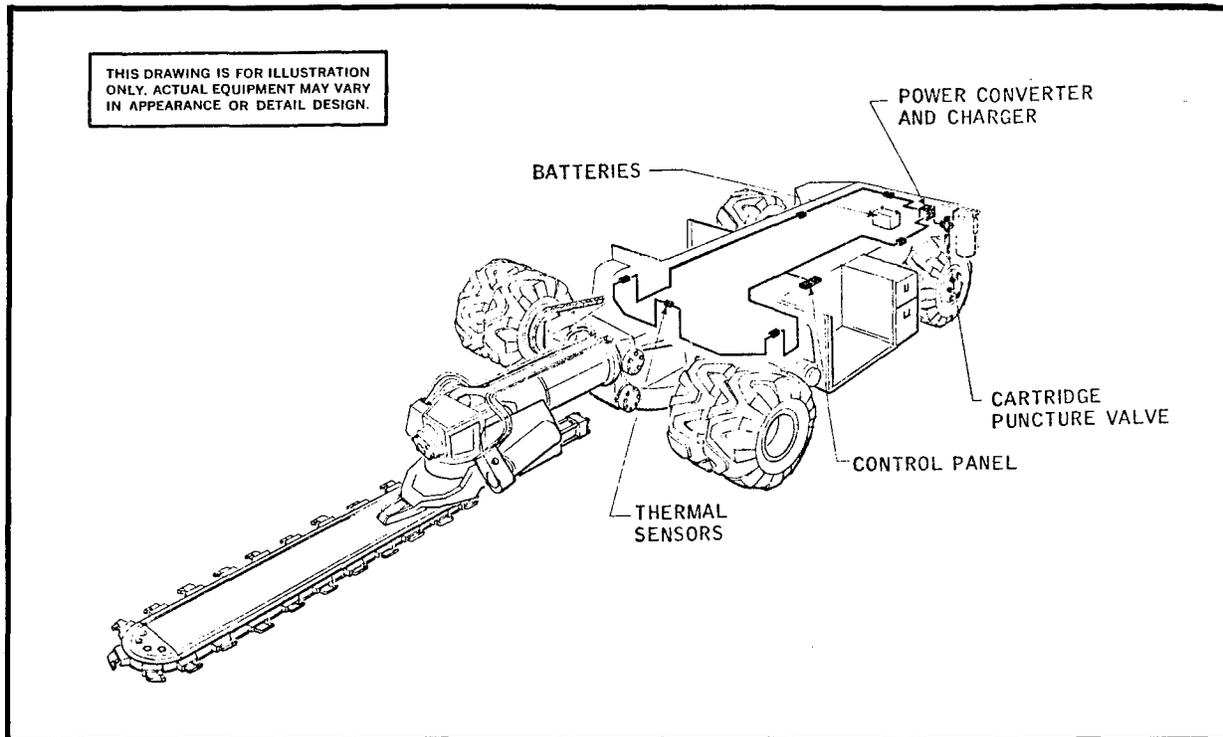


Figure 44 ARTIST'S CONCEPT, SYSTEM V INSTALLATION ON GOODMAN 2500 CUTTER

Six parallel-loop-connected, bimetallic, thermal-switch sensors were installed in the following locations on the cutter:

- Cable reel housing
- Motor and reservoir area
- Hydraulic pump and hose area.

The cost-effective, rate-of-rise-type point sensors appeared better suited to a compartmentalized vehicle such as the cutter than the continuous-heat-sensing wire. The point sensors are set to alarm at 225°F except where high heat zones warrant a 325°F set point.

The control panel was mounted near the left side of the vehicle near the operator. The battery box and cartridge-puncture solenoid valve were similarly located.

3.8.1.4 Caterpillar 988 Loader (Figures 45 through 47)

A modification of automatic fire sensing System III was selected for installation on the Caterpillar 988 loader (see Figure 48). This high-priority production vehicle is similar to the unit that was completely destroyed by fire at the mine.

Modifications were made in the fire control panel to "float" the ground path to be compatible with the loader master switch in the negative lead of the battery. The floating ground circuit of the fire control panel and the isolated thermal-point sensors allow automatic fire protection with the vehicle power (master switch) in the OFF position.

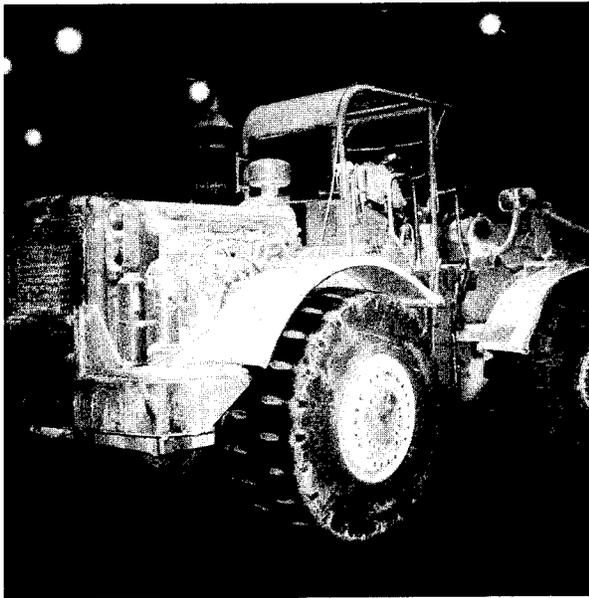


Figure 45 FRONT-END LOADER VEHICLE



Figure 46 MECHANIC INSTALLING JUNCTION BOX IN OPERATOR'S CAB (Note Center Control Panel and Solenoid Valve on Right of Photo)



Figure 47 HEAT SENSOR MOUNTED TO ENGINE COVER OF FRONT-END LOADER (Note Wire Disconnect to allow Removal of Engine Cover)

Because the ground jacket of the outer shield of the thermal-wire sensor is incompatible with the switched-ground vehicle, six point sensors were installed in the following areas of the vehicle:

- Two on the engine hood, with disconnects on each side (to ease maintenance)
- Two high and aft near the radiator
- Two low and forward over the transmission.

As before, parallel-loop connections were used to allow for continuous monitoring and system functioning even if a pair of wires were broken. (The broken wires would provide a yellow FAULT indication but the system would function in case of fire.)

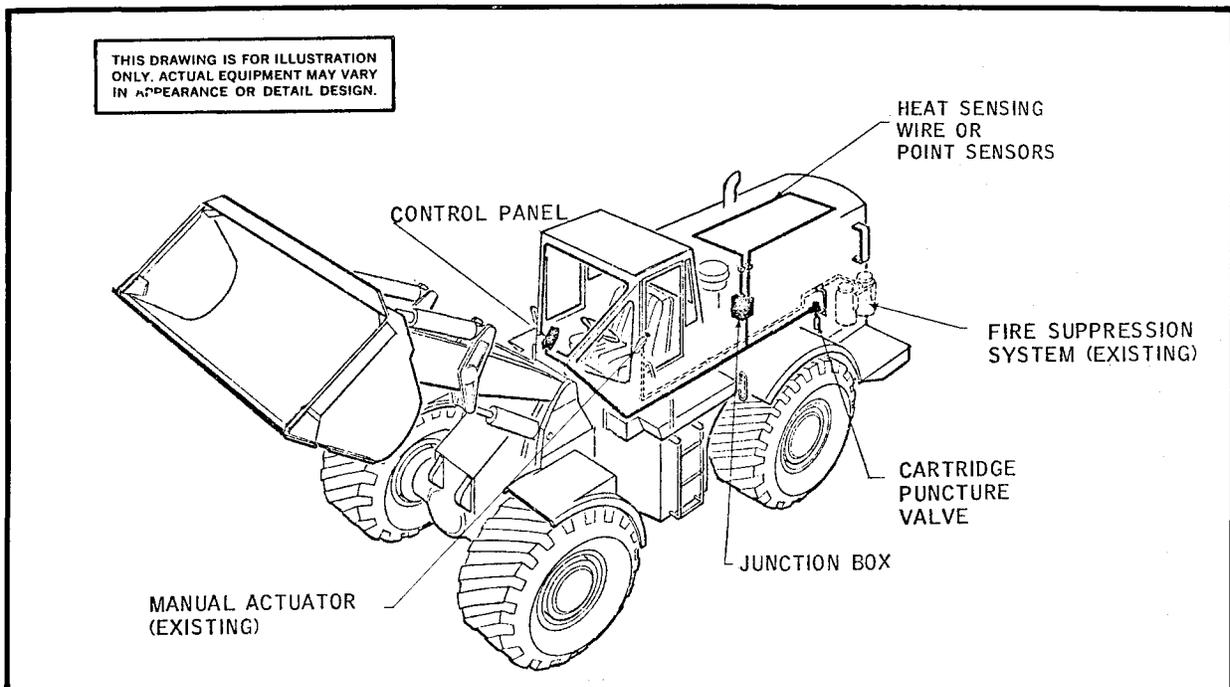


Figure 48 ARTIST'S CONCEPT, SYSTEM III INSTALLATION ON CATERPILLAR 988 FRONT-END LOADER

The normally open, rate-of-rise sensors close at 225°F and 325°F to signal a fire alarm. A short circuit in the sensor electrical circuit will also provide a fire signal, however.

The loader installation specified that the fire system 24-volt power be supplied directly from the terminal posts of the battery, being first routed through the system junction box mounted behind the operator and then to the control panel bolted to 1-1/2- by 1-1/2-inch angle brackets forward and overhead on the cab structure. The cartridge-puncture valve was mounted to the cab and plumbed in series with the existing manual fire suppression system.

At the completion of approximately 12 man-days of installation effort, two systems (crane and cutter) were operational but were not connected for automatic discharge. A trial operating period was desired to prove the system integrity and to correct placement of sensors, heat ranges, and false alarms. The desire to instruct all operators in the use and awareness of the system was another reason to delay connection of the automatic discharge systems.

The completion installation of the fire protection system on the loader was delayed because of the unavailability of the high-priority production vehicle for installation activity.

3.8.2. Installation of the Automatic Fire Protection Systems, Jim Bridger Coal Mine

The Jim Bridger mine is approximately 35 miles east of Rock Springs, Wyoming. The 185-million-ton coal reserves on the 17,500-acre facility are split into two seams that extend over an area 4,000 feet wide and 10 miles long. The upper deadman seam, averaging 15 feet in thickness, is separated from the lower deadman seam, averaging 12 feet in thickness, by a nominal 20-foot parting. Mining takes place from the outcrop to a depth of approximately 200 feet. Mobile mine equipment at the mine includes the following units:

- Ten Wabco 75C trucks with 120-ton bottom-dump coal hauler trailers
- Four Wabco 75C trucks with rear-dump ash hauler trailers

- Two Bucyrus-Erie 195-B shovels with 18-cubic-yard dippers
- One Caterpillar 992 front-end loader
- One Page 732 dragline with 18-cubic-yard bucket
- One Marion 8200 dragline with 70-cubic-yard bucket.

Each item of mining equipment is equipped with portable dry-chemical fire extinguishers and the draglines are equipped with fixed CO₂ fire suppression systems protecting the transformers and oil storage areas.

The mine vehicles have experienced fires in the past and management is aware of the hazards and costly repair, replacement, and production losses that fires represent. This contract provided for equipping three mobile vehicles with automatic fire sensing and suppression systems and equipping a dragline with an automatic alarm system. The four selected vehicles were monitored for 10 months and discharge demonstrations of the automatic fire protection systems concluded the program in November 1977.

The automatic fire protection system installations were performed during the week of 14 February 1977 on one Wabco coal hauler, one Wabco ash hauler, one Caterpillar 992 loader, and one Marion 8200 dragline. All systems were initially installed according to previous contract guidelines except for the Caterpillar loader. The loader was modified in a manner similar to the modification of the Caterpillar loader at Diamond Crystal mine by using point heat sensors and obtaining 24-volt power directly from the battery, thus bypassing the master switch.

3.8.2.1 Wabco 120-Ton Coal Hauler Truck (Figures 49 through 53)

The automatic fire protection system selected for this vehicle was System I which is described in Subsection 3.5.1 and illustrated in Figure 11. Figure 54 depicts installation of System I on a Wabco 120-ton truck.

Installation proceeded using criteria established from previous work on large off-road vehicles as follows:

- The four optical flame sensors were mounted high and away from mud-slinging tires and under the engine hood and A-frame to observe the exhaust and turbo-charger areas.

- The 16-foot-long heat-sensing wire was arranged in a looped-circuit, U-shape, with legs extending forward over the exhaust manifolds, then routed under the A-frame at the rear of the engine.
- The two stored-pressure cylinders containing dry-chemical extinguishing agent were mounted on the right front corner of the platform.
- Four nozzles from one cylinder are the 180-degree fan pattern type that are pointed to divide the flow of extinguishing agent to half above and half below the exhaust manifolds in the engine area. Two of the four nozzles from the second cylinder are the same 180-degree fan type and point to split equal flow over the transmission. The remaining two units are 360-degree cone-shape nozzles, one each pointed to the oil reservoir and diesel fuel tank that are saddle mounted to the rear frame.
- The junction box, remote switch, and ambient temperature probe sensor were installed on the left fender near the ladder.
- The control panel was mounted to the roof of the operator's cab.

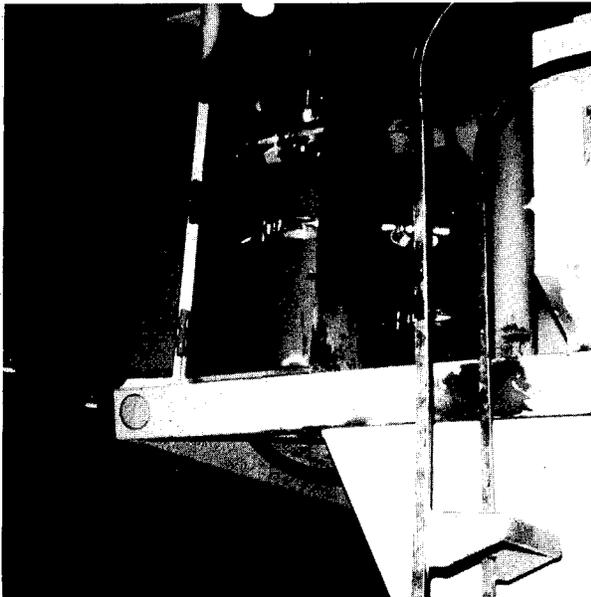


Figure 49 PRESSURIZED CONTAINERS WITH DRY POWDER CHEMICAL



Figure 50 120-TON COAL HAULER

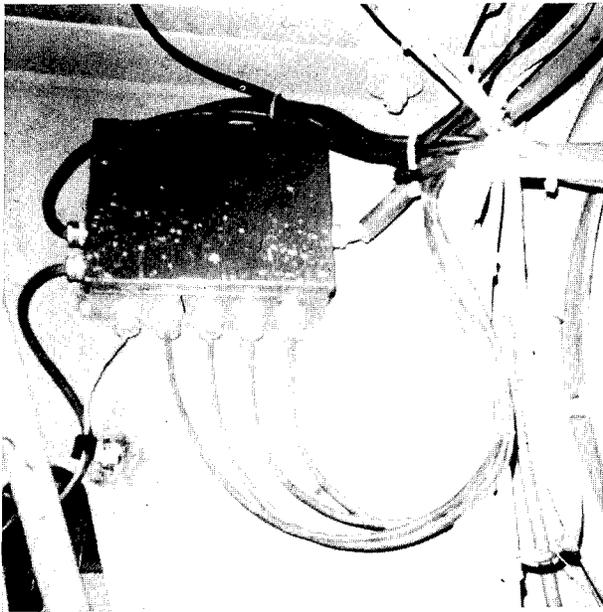


Figure 51 JUNCTION BOX MOUNTED INSIDE FRONT FENDER

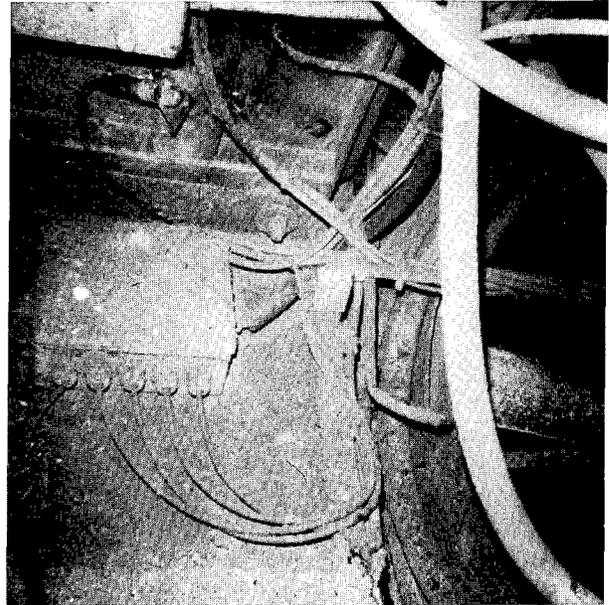


Figure 52 JUNCTION BOX AFTER SEVERAL MONTHS OF PRODUCTION (Note Optical Flame Sensor Above Box)



Figure 53 REMOTE ACTUATOR NEAR LADDER (Note Ambient Temperature Sensor at Left Side of Switch)

As with previous fire system installations involving routing of hoses and wires, and, consequently, possible added maintenance for removal or replacement when servicing the vehicle system, all items were fixed to frame members or vehicle components not normally removed or serviced. The engine, transmission, hydraulics, or electrical vehicle systems can be serviced and repaired without disturbing components of the fire protection system.

The solenoid valves of the system were not connected for automatic discharge until a reasonable trial

period proved satisfactory system integrity and failure to false alarm. Operator awareness was also a consideration for not immediately connecting the system for automatic discharge.

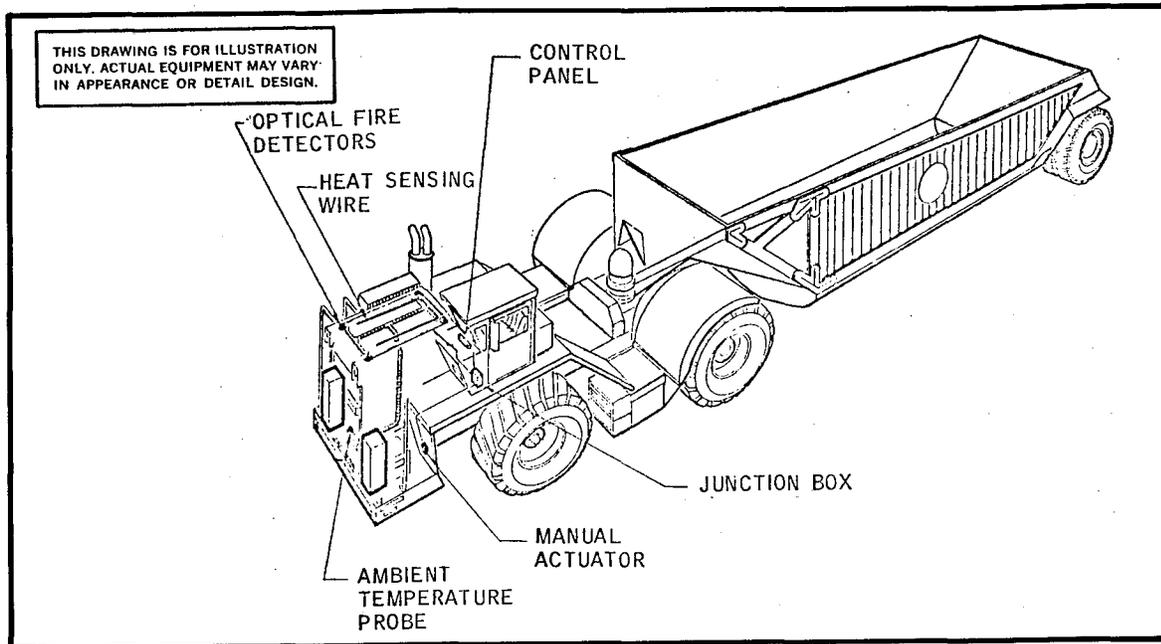


Figure 54 ARTIST'S CONCEPT, SYSTEM I INSTALLATION ON WABCO 120 TRUCK

The fire protection control panel stopped functioning after being installed for approximately three working shifts; however, power had been applied for only 5 to 10 minutes. Return of the panel to FMC and subsequent repair determined that failure was a result of faulty assembly when a component (regulator) was being resoldered for isolation. Excess solder on the collector of transistor Q101 caused a short circuit. Although laboratory testing after assembly confirmed satisfactory operation, shipping to the mine and vibration after installation apparently accelerated the problem.

3.8.2.2 Caterpillar 992 Front-End Loader (Figures 55 through 59)

Difficulty was again experienced with vehicle availability, and the fire system installation on the Caterpillar loader was not fully completed during the February visit. System II, used for this installation, is described in Subsection 3.5.2 and illustrated in Figure 12. Figure 60 depicts System II installed on Caterpillar loader.

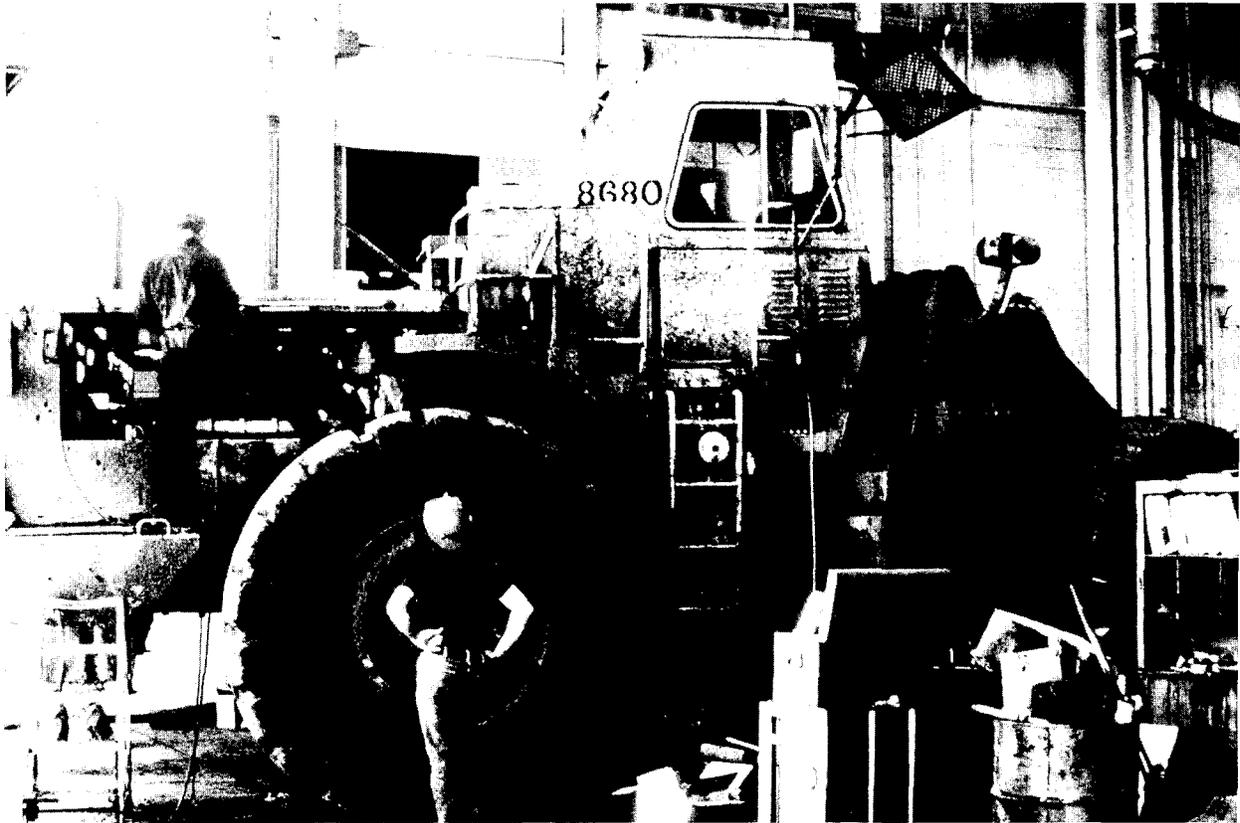


Figure 55 INSTALLING FIRE PROTECTION SYSTEM ON FRONT-END LOADER

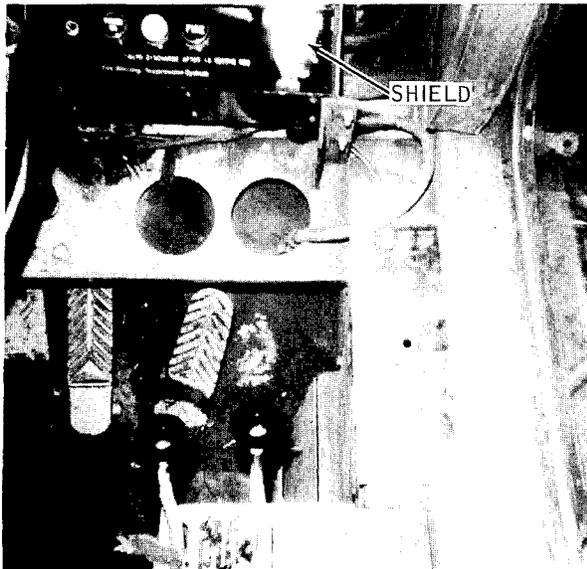


Figure 56 CONTROL PANEL WITH SHIELD OVER MANUAL ACTUATOR



Figure 57 WELDER REPAIRING CRACKED MOUNTING BASE OF CYLINDER HOUSING

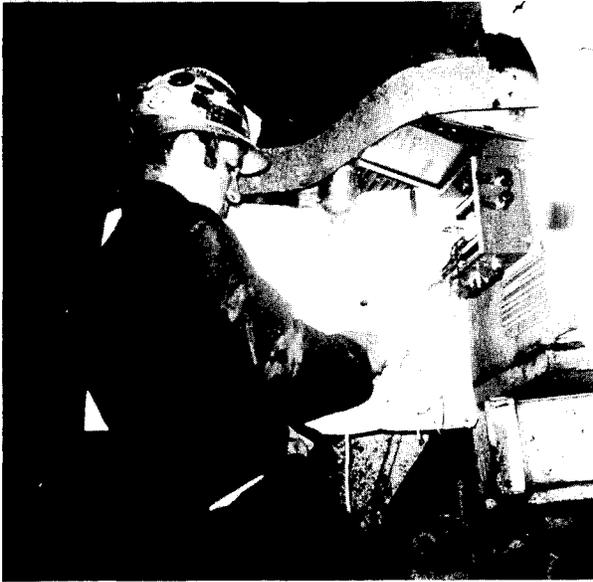


Figure 58 WIRING JUNCTION BOX UNDER PLATFORM

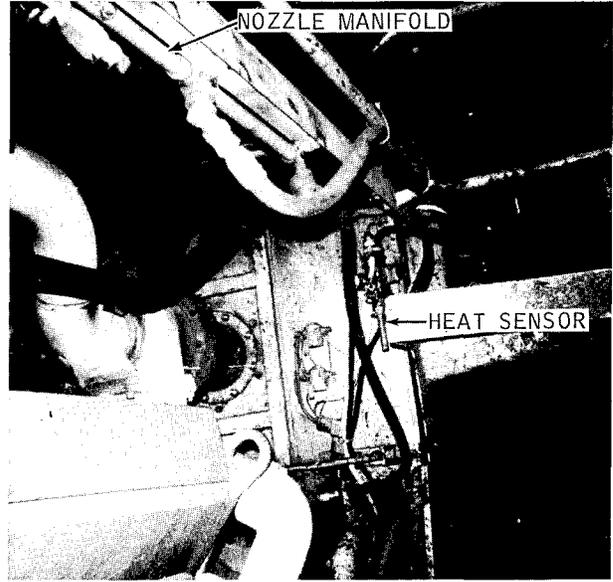


Figure 59 DRY-CHEMICAL DIS-CHARGE MANIFOLD ON ENGINE COVER (Note Heat Sensor on Firewall Near Platform)

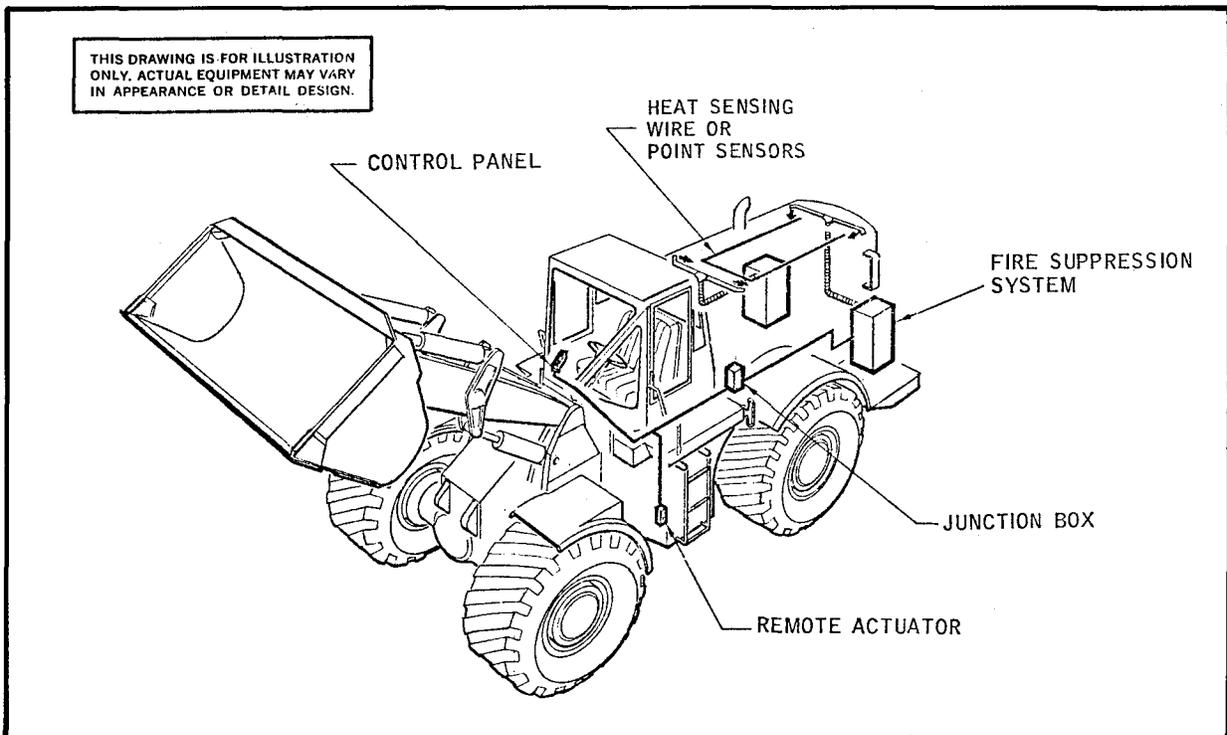


Figure 60 ARTIST'S CONCEPT, SYSTEM II INSTALLATION ON CATERPILLAR 992 FRONT-END LOADER

The Caterpillar 992 vehicle, designated by the mine for installation of an FMC/USBM automatic fire protection system, was out of service the entire week because of a damaged engine, and availability immediately after repair was unlikely because of production scheduling. Seventy-five percent of the vehicle was disassembled. Because of the engine maintenance and repair priority, February installation of the automatic fire protection system was limited to welding brackets in the cab to mount the control panel and fabrication of several brackets for future installations of the two fire suppression cylinders that contain the dry-chemical agent.

The vehicle electrical system was similar to that of the Caterpillar 988 vehicle at Diamond Crystal mine (i.e., the 24-volt DC negative ground is through the master switch); therefore, the ungrounded, thermal point-type sensors were used rather than the 16-foot, grounded, heat-sensing wire. Also, the fire protection system was connected directly to the battery to be active at all times, as with Diamond Crystal vehicles.

During the 13 June visit, the remaining components were installed:

- Six thermal point sensors surround the engine and transmission areas.
- Rather than mounting two sensors directly on the engine hood as at Diamond Crystal, thus requiring disconnect plugs to remove the hood and servicing the engine, all sensors were mounted on the vehicle frame.
- Two stored-pressure cylinders, each containing 30 pounds of ABC dry-chemical extinguishing agent, were mounted to the operator's platform. The four nozzles from each cylinder were mounted on the engine hood. Three nozzles are 180-degree fan type pointing toward the engine with discharge flow divided over top and bottom. The third nozzle points forward into the transmission area. Two 3/4-inch hose connections must be removed to disconnect the nozzle manifold and remove the hood.
- The junction box was installed to the frame under the right platform and the control panel was bolted to 1-1/2- by 1-1/2-inch angle brackets welded to the instrument panel in the cab. This was the only installation where the control panel was mounted in a near-vertical position. The unique position was necessary because of space limitations and restrictions for drilling or welding to the certified ROPS cab structure.

- The remote actuator switch was mounted to the left rear corner of the vehicle.

As with all automatic fire protection systems, the solenoid coils were left off the extinguisher cylinder valves immediately after installation so that the system could operate over a trial period without possible nuisance alarms causing false discharges. During this period, proper temperature ranges, sensor locations, or circuit problems would be corrected as necessary. Also, operators and mechanics could become familiar with the components and accidental discharges could be avoided.

3.8.2.3 Wabco 120-Ton Ash Hauler (Figures 61 through 65)

The automatic fire sensing system for this vehicle was System III which is described in Subsection 3.5.3 and illustrated in Figure 13. Installation of System III on a Wabco 120-ton truck is depicted in Figure 66.



Figure 61 ASH HAULER VEHICLE



Figure 62 FIRE CONTROL PANEL
IN OPERATOR'S CAB
(Note Manual Actuator
on Door Post)



Figure 63 DRY-CHEMICAL CON-
TAINERS OF ANSUL A101
MANUAL FIRE SUPPRES-
SION SYSTEM

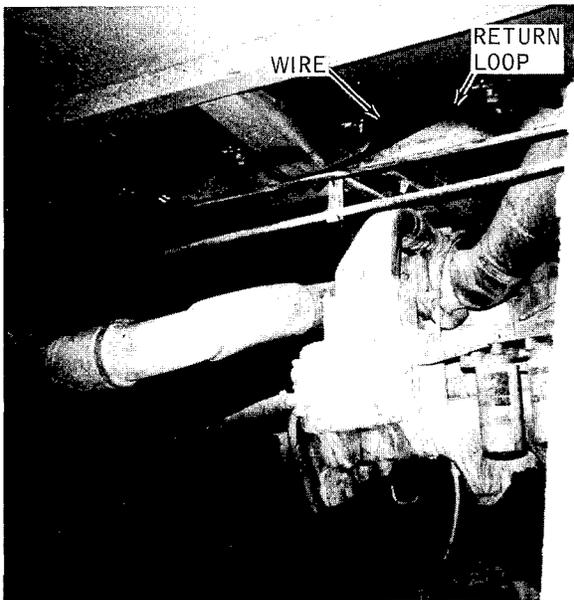


Figure 64 HEAT-SENSING WIRE
DETECTOR IN ENGINE
AREA

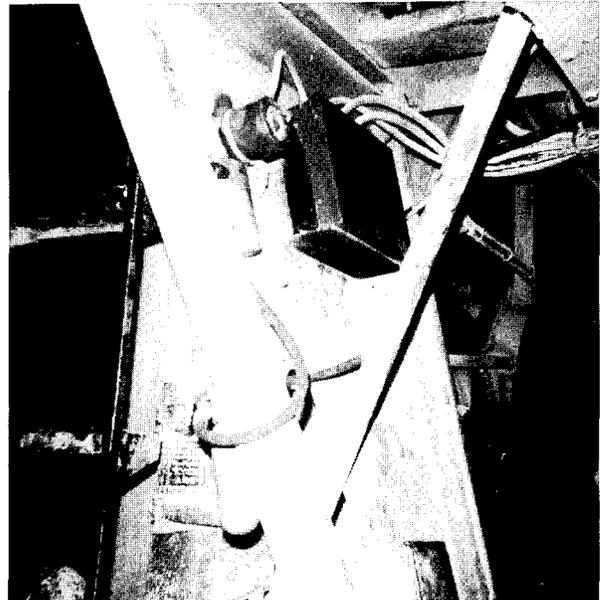


Figure 65 CARTRIDGE-PUNCTURE
SOLENOID VALVE AND
JUNCTION BOX (Note
Manual Actuator
Cartridge Lower Center
Photo)

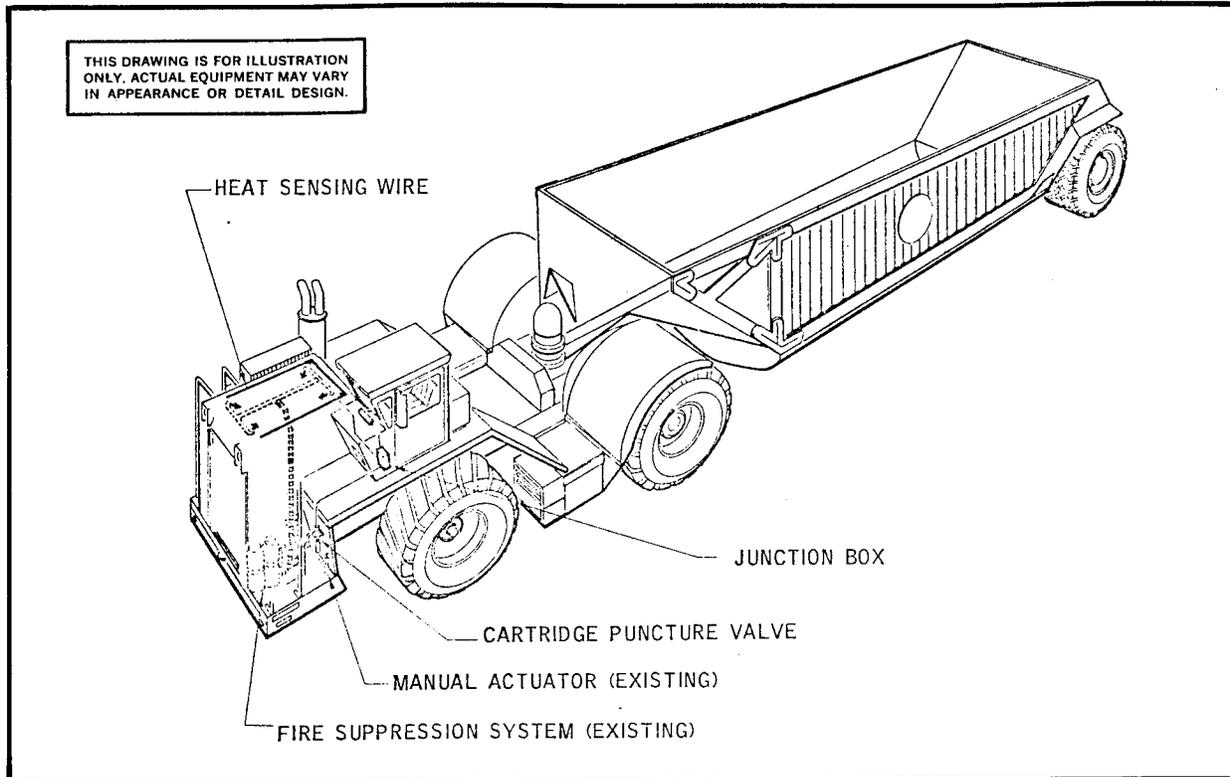


Figure 66 ARTIST'S CONCEPT, SYSTEM III INSTALLATION ON WABCO 120 TRUCK

Except for having electrical power routed from the 24-volt DC batteries through a master switch, thereby providing an automatic 3-second test during engine start, the system is identical to those used on the truck and crane vehicles at the Diamond Crystal mine. It is an overheat alarm warning system connected to an existing, fixed, manually activated fire protection system. The control system will automatically activate discharge of dry chemical fire suppression agent 10 to 13 seconds after audible/visual FIRE alarm.

A manual fire suppression system had not already been installed, as at Diamond Crystal; therefore, mine management agreed to purchase and install a system so that the Bureau of Mines proposed test effort could be accomplished.

All components of the automatic fire sensing system were installed and functioning during the February installation; however, the manual fire suppression system had not arrived and could not be installed and

interconnected for automatic discharge. However, because the design policy was to install the automatic system for a trial period without connecting for automatic discharge, lack of the manual system was not immediately significant.

The heat-sensing wire, junction box, and control box were mounted in identical positions as in the coal hauler. The new cartridge-puncture solenoid valve was located inside the left front fender next to the junction box and near the anticipated location of the remote manual actuator.

The Ansul A101-30 manually actuated fire suppression system was received and installed during June. All required hose and fittings for the two dry-chemical containers, two actuators, and eight nozzles were purchased and necessary brackets were made to install the fire suppression system. The hose from the automatic actuator device was then connected to the actuator hose of the Ansul fire suppression system. The dry-chemical containers and nozzle assemblies were located and positioned identically to the coal hauler vehicle. One manual actuator was located in the cab and another at ground level near the ladder.

3.8.2.4 Marion 8200 Dragline (Figures 67 through 71)

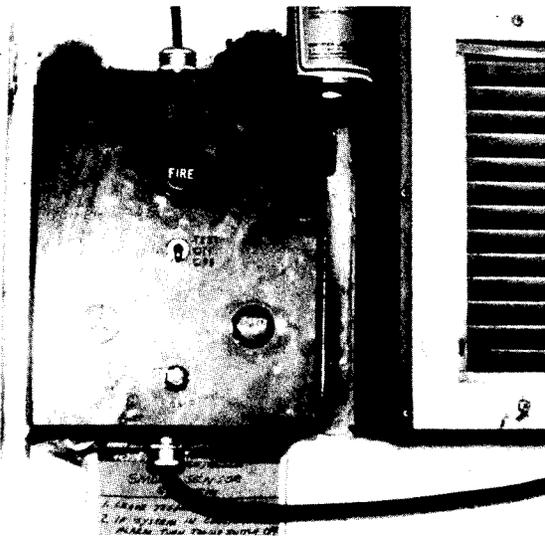


Figure 67 FIRE CONTROL PANEL
IN DRAGLINE OPERATOR'S
CAB

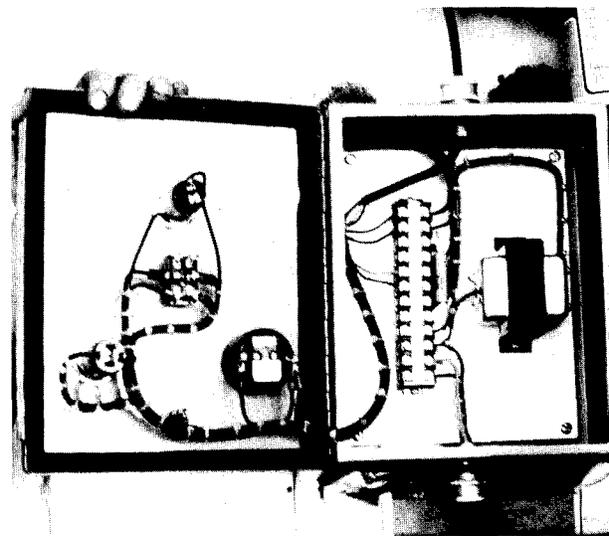


Figure 68 INSIDE OF CONTROL
PANEL

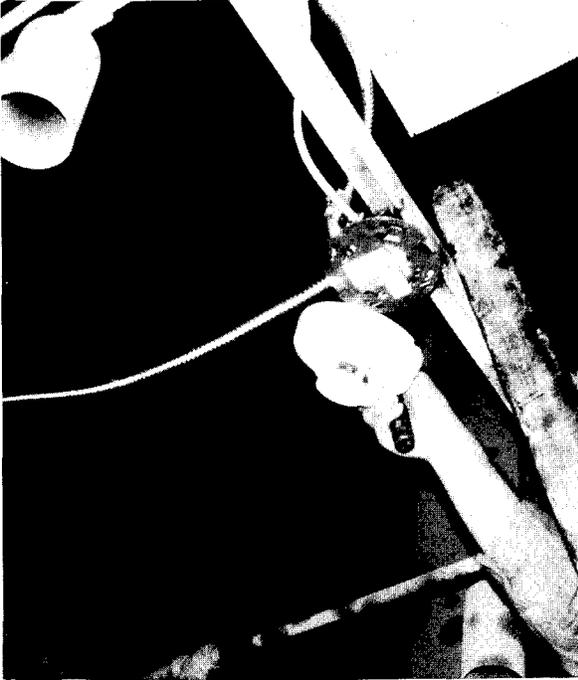


Figure 69 SMOKE DETECTOR
OVER OIL STORAGE
AREA (Mounted Flat)



Figure 70 DUST COLLECTED
IN SMOKE DETECTOR
OVER OIL STORAGE
AREA

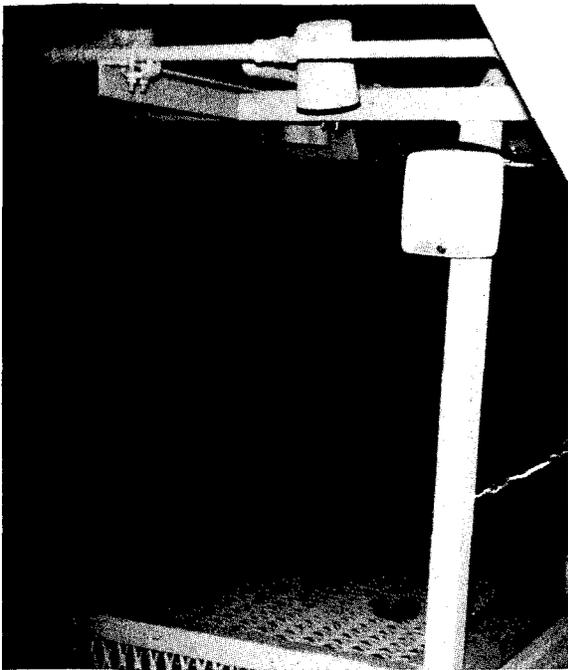


Figure 71 SMOKE DETECTOR
OVER TRANSFORMER
(Mounted Vertically)

The large dragline vehicle was equipped with CO₂ extinguishing and pneumatic heat-sensing systems to protect the oil storage area and transformer.

Early alarm of a fire situation area was considered equally important for this vehicle as for others, thus allowing an opportunity to evaluate smoke detectors of System IV. See Sub-section 3.5.4 and Figure 14 for a complete system description.

Figure 72 is an artist's concept of System IV installed on a dragline vehicle.

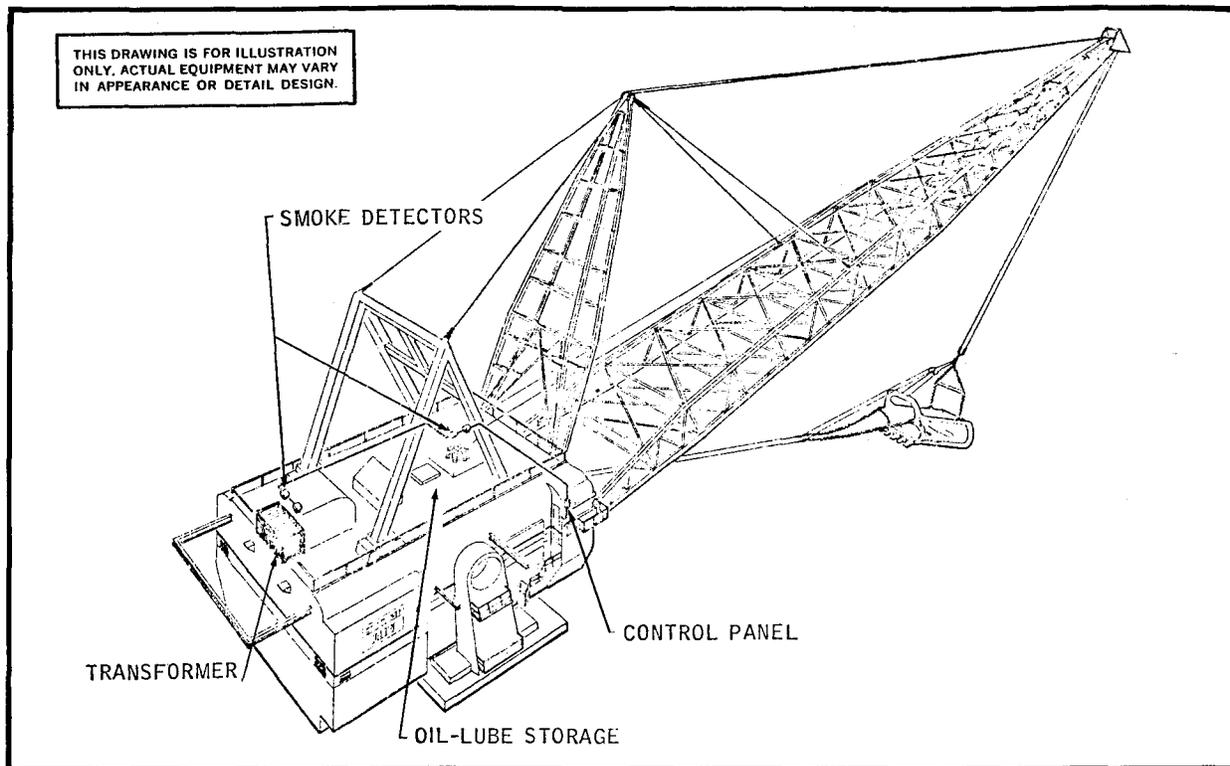


Figure 72 ARTIST'S CONCEPT, SYSTEM IV INSTALLATION ON M8200 DRAGLINE

The two photoelectric smoke detectors are interconnected to a control panel in the operator's cab. Early warning of smoke from the oil storage or transformer areas will provide an audible and visual alarm. The smoke detectors are not interconnected for automatic discharge of the existing CO₂ fire extinguishing system because manual actuators are readily available throughout the vehicle. Should the vehicle be unattended during a possible fire, thus not presenting a personnel hazard, the existing backup (but slower-response) heat sensors will automatically discharge the CO₂ system.

Each sensor is connected directly to 110-volt AC electrical power, to each other, and to the fire control panel. One Pyrotector Model 30-52TC smoke detector is vertically mounted (as is a wall-mounted unit) over the transformer, whereas a Model 30-40RC detector is mounted horizontally over the oil storage area similar to a ceiling-mounted unit. No special precautions were taken during installation except for the required power lines being contained in flexible metal conduit.

The smoke detectors were mounted to standard, residential-type electrical boxes that were welded to the structure supporting the CO₂ nozzles and heat sensors. This mounting later proved unsatisfactory, and the horizontally mounted detector became contaminated with dust. The vertically mounted detector performed well throughout the 10-month testing period.

At the completion of approximately 16 man-days of effort, the systems on the coal hauler, ash hauler, and dragline were operational but not connected for automatic discharge until a trial operating period proved satisfactory system integrity, correct sensor location and heat ranges, and system failure to false alarm. The front-end loader required another 3 man-days for completion of component installation. Another 2 man-days were required of the mine personnel to install the Ansul A101-30 manual fire protection system.

3.8.3 Monitoring of the Automatic Fire Protection Systems

Monitoring of the automatic fire protection systems at Diamond Crystal mine and at Jim Bridger mine was accomplished by weekly telephone calls to mine personnel cognizant of the installations and/or by special trips by FMC personnel to the mine to inspect each system and to make repairs where necessary. A summary of several events occurring during the 11-month monitoring period at Diamond Crystal and the 10-month period at Jim Bridger is shown in Table 5.

Table 5 SUMMARY OF MONITORING EVENTS

Mine name	Test duration, months	Total visits including installation monitoring and demonstration	Number of fire control panels replaced	Fire system activations		Replaced/repaired actuator device		Sensors failed or replaced	
				Discharged agent (includes demonstration)	Alarm - no discharge	Cartridge puncture type	Stored pressure type	Quantity	Type
Diamond Crystal mine	11	5	3	6	5	4	N/A	2	Point
Jim Bridger mine	10	6	2	4	5	0	2	1	Smoke
Total		11	5	10 ¹	10 ²	4	2	3	-

1. Seven intentional during demonstration. 2. Five not connected for discharge.

As mentioned in Subsection 3.8.1, it was anticipated that appearance of a fire control panel would cause interest and some questions among the various operators of the mine equipment. The systems were, therefore, not activated for automatic discharge until the mine personnel became more aware of the system function. The manual PUSH-TO-DISCHARGE button on the control panel was sealed with a shear-wire so that accidental system activations could be identified over those activations caused by shock or vibration.

Of twenty total system activations, seven were intentional as the result of the final demonstrations, seven were readily identified, and only six were unidentified. In all but one of the six unidentified activations, the seal wires were found broken on the manual PUSH-TO-DISCHARGE button, indicating probable activation by inadvertent manual discharge. The one unexplained activation that caused the dry-chemical agent to discharge occurred when the operator was starting the diesel engine. A stray voltage transient is tentatively considered at fault.

3.8.3.1 Monitoring Activities, Diamond Crystal Mine

Monitoring of four automatic fire protection systems continued from the 10 January 1977 installation until the final demonstration tests conducted 10 November 1977.

As shown in Figure 73, many significant events were identified. The following additional details are supplied for understanding of the chart:

- Use of modified Systems III or V indicate there was some change to the system as presented in Section 3.5 before the system was installed on a vehicle. Generally, the modifications involve bypassing the master switch or a change in sensor selection.
- Monitoring interruption was caused by a re-evaluation of the contract goals. Telephone contacts were maintained, but events either did not occur or were insignificant to report.
- In May and again in October, a yellow FAULT light on the loader indicated probable wiring error during installation or repair. The six thermal point sensors require 16 electrical connections with a pair of wires; four are disconnect plugs and the others are in sealed conduit fittings. An open circuit at one connection was the primary cause for the FAULT condition.

Installation	Monitoring and events											
	January	February	March	April	May	June	July	August	September	October	November	
System III, Euclid R35 truck (1)	Mine visit - install (Jan 10) Subcontract and insurance certificates approved 13 Dec 1976	Monitoring interrupted Feb 25	No significant data recorded	No significant data recorded	Mine visit (May 16) Monitoring resumed May 13 Replaced control panel and valve Changed vehicle to neg ground Replaced battery connections	Manually actuated -- powder not expelled due to open air line Control panel malfunction - changed circuit breaker	No significant data recorded	Mine visit (Aug 24) Mine electrician corrected panel circuit breaker problem	Mine visit (Sept 12) Electrical fire 9-2-77, Amsul system manually actuated. Starter cable replaced. System discharged 9-16-77, low voltage suspected	System refurbished after discharge	Mine visit (Nov 10) Fire test demonstrated automatic features System demonstrated without prior maintenance	
System V, Galion 125 Crane (2)			Power interruption caused alarm	Mine visit (May 16) Installed larger batteries	No significant data recorded	Vehicle collision destroyed control panel, valve and ma in cable 7-22	Mine visit (Aug 24)	Mine visit (Sept 12) System refurbished following vehicle repair of (16)	No significant data recorded	Mine visit (Nov 10) Fire test demonstrated automatic features		
System V, Goodman 2500 Cutter (3)			System actuated but did not discharge powder	Mine visit (May 16)	System actuated and discharged	No significant data recorded	Mine visit (Aug 24) System actuated. Bent pin failed to puncture cartridge	Mine visit (Sept 12)	System alarmed at low voltage	Mine visit (Nov 10) Fire test demonstrated automatic features		
System III, 988 Caterpillar Front-end loader (4)			No significant data recorded	Mine visit (May 16) Replaced battery connections Yellow fault light not resolved	No significant data recorded	No significant data recorded	Mine visit (Aug 24) Replaced control panel and valve Steam cleaning system activates system Left front sensor repaired	Mine visit (Sept 12) System actuated but did not discharge powder Left front sensor replaced	Yellow fault light not resolved	Mine visit (Nov 10) Fire test demonstrated automatic features		
	<p>(1) Activation for automatic discharge occurred May 16, 1977. (2) Activation for automatic discharge occurred in March, 1977. (3) Activation for automatic discharge occurred in March, 1977. (4) Activation for automatic discharge occurred November 10, 1977.</p>											

Figure 73 IN-MINE MONITORING SUMMARY, DIAMOND CRYSTAL MINE

- Manual activation without discharging dry chemical occurred during June on the truck when an operator admittedly bumped the PUSH-TO-DISCHARGE button. No chemical was expelled because a hose on the series-connected Ansul actuator was found disconnected, allowing pressure to escape before discharging the system. Check valves on systems with multiple actuators are recommended.
- A control panel malfunction during June on the Euclid truck is related to the mine electrician-corrected control panel of August. After the accidental manual discharge in June, the replacement control panel (May) did not function properly and an investigation was initiated. After determining the problem was related to the control circuit, another control panel was installed. This panel incorporated a 1/2-ampere circuit breaker in the solenoid output which was insufficient to discharge the valve until the mine electrician installed the proper 3-ampere circuit breaker.
- An electrical fire occurred on the test vehicle truck 2 September 1977 in the starter motor area. The smoke was observed by the driver who activated the Ansul fire suppression system. A telephone investigation and analysis of the incident are recorded in Appendix G.
- A system discharge occurred on the truck in October during starting. This problem is unexplained except that it may be an extension of repeating nuisance alarms during low-voltage conditions.
- Although the control/logic systems have performed well when 18- to 32-volt DC power is available, the electronic circuit has experienced a low-voltage problem when available power is less than 18 volts. Also, low crossover (inductive) voltage causes signals to appear when main power is off.
- Erroneous signals appeared several times during the 11 months of monitoring. Initial investigation revealed that extensive design analysis and test would be required to find the problem and additional shop and engineering labor would be necessary to correct the existing units. Further action was not taken because the problems appear minor and non-hazard-producing, and occur only when power is below the design tolerance of the system. They are not repeatable and have not occurred during other known low-voltage conditions. Unfortunately, it appears customary that mine vehicle electrical systems do not receive the

extent of preventive maintenance that the mechanical portions of the vehicle receive (i. e., engines, transmissions, differentials, tires, etc.). Broken electrical terminal strips, frayed cables, broken or damaged connectors, open wires, open cells on lead-acid batteries, and loose connections are some conditions that often are not corrected until some resulting mechanical failure occurs.

- A vehicle collision involving the crane during July destroyed much of the vehicle, the automatic fire sensing system, and the Ansul fire suppression system. The cartridge-puncture valve, control panel, and main cable required replacements, as well as both Ansul dry-chemical containers.
- System activation was reported on the cutter vehicle in April and again in June. A telephone investigation and analysis are recorded in Appendix H for the June incident.
- A bent pin was found in the activated cartridge-puncture solenoid valve of the crane during an August inspection trip. The pressurized cartridge was not punctured because the pin was lodged in the seal-thread groove. A stronger pin shaft was suggested to prevent bending.
- The left front sensor on the Caterpillar 988 loader was repaired twice during the 11-month monitoring period and again prior to the demonstration. It was initially located in a vulnerable position near the rear tire.

The preceding paragraphs and the appendixes provide several highlights of the monitoring period for the automatic fire protection systems at Diamond Crystal mine. The following statements summarize this activity:

- Only after adequate sealing is performed are the electrical control panels capable of surviving the mine conditions when subjected to steam cleaning in a salt dust environment. All sensors performed well when protected from physical damage.
- Low-voltage conditions cause abnormal system operation. A reliable power supply to maintain 18 to 32 volts DC is very important. The manual PUSH-TO-DISCHARGE buttons should be adequately guarded from accidental actuation.

- Electrical and mechanical maintenance should be performed by several persons cognizant of each system design. Maintenance proved difficult initially because only one electrician performed the installation. After several months of telephone calls, correspondence, and visits, other persons became familiar with and were able to troubleshoot the systems.

3.8.3.2 Monitoring Activities, Jim Bridger Mine

The four fire protection systems installed on equipment at the Jim Bridger mine were monitored for 10 months, from the 14 February 1977 installation until the final demonstration tests 15 November 1977.

As shown in Figure 74, many events were identified several of which warrant additional explanation:

- The control panel on the coal hauler was replaced in January because of a faulty solder connection following modification of the circuit to float the ground path. The control panel on the loader was replaced in October because of a circuit board failure. Small amounts of coal dust entering the loader panel may have caused electrical shorts between the printed-circuit traces.
- Nitrogen pressure in the two coal hauler valves with FMC-fabricated Neoprene seals was closely monitored. The seals were made to replace factory-supplied Teflon seals that slowly leaked pressure. The Automatic Switch Company, manufacturer of the 3/4-inch, two-way, pilot-operated valve, elected to investigate alternate materials other than Neoprene because of possible bonding failures under high-pressure conditions. No leakage from the Neoprene-sealed valves occurred during the period February to June.
- Low pressure was noted in the coal hauler valves (with Neoprene seals) during the September visit and new factory-supplied cast urethane valve seals were installed. Although the cylinder pressure was low (360 to 400 psig), the yellow FAULT light had not yet appeared and the system would have provided effective discharge in event of a fire.
- Periodic illumination of red/yellow indicator lights on the coal hauler was reported during June. Correction of a vehicle electrical short in the transmission shift system resolved most inadvertent alarms, but inductive voltage or transients occasionally cycled the system through a test condition.

Installation		Monitoring and events											
January	February	March	April	May	June	July	August	September	October	November			
System I Wabco 120T Coal hauler (1)	Mine visit - install (Feb 14) Monitoring in- terrupted Feb 25 Subcontract and insurance certificates approved Feb 9, 1977 Control panel replaced	All systems reported functional	No significant data recorded	Monitoring re- summed May 13	Mine visit (June 13) Pressure with Teflon seals OK Reported red/ yellow lights illuminate periodically Correcting vehicle shorts solved problems	No significant data recorded	USBM visit/ safety class (Aug 17)	Monitoring during production	Mine visit (Oct 3) Pressure with Teflon seals OK Monitoring during production Electrical inter- ference from vehicle light circuit	Mine visit (Nov 15) Fire test demon- strated automatic features System demon- strated without prior maintenance			
System II Caterpillar 992 Front end loader (2)	Mine visit - install (Feb 14) Monitoring in- terrupted Feb 25 Subcontract and insurance certificates approved Feb 9, 1977				Mine visit (June 13) Changed leaking Teflon seals to illuminate periodically		USBM visit/ safety class (Aug 17) Manually actu- ated, no dis- charge because of system not active Solenoid coils missing	Mine visit - in- stall (Sept 24) Vehicle un- available	Mine visit (Oct 3) Control panel replaced Pressure with Teflon seals OK Replace sol- enoid coils Partial dis- charge Oct 17	Mine visit (Nov 15)			
System III Wabco Ash hauler (3)	Mine visit - install (Feb 15) Monitoring in- terrupted Feb 25 Subcontract and insurance certificates approved Feb 9, 1977				Mine visit (June 13) Installed Ansil suppression system		USBM visit/ safety class (Aug 17) Blown engine, Aug 15	Mine visit - in- stall (Sept 24) Electrical inter- ference from vehicle light circuit	Mine visit (Oct 3) Monitoring during production Rewired to by- pass master switch Yellow fault light Oct 17	Mine visit (Nov 15) Fire test demon- strated automatic features System had dis- charged causing partial discharge			
System IV Marion 8200 Dragline (4)	Mine visit - install (Feb 15) Monitoring in- terrupted Feb 25 Subcontract and insurance certificates approved Feb 9, 1977			Dust caused steady alarm; cleaned with air	Mine visit (June 13) Dust caused steady alarm; cleaned with air		USBM visit/ safety class (Aug 17) Dust caused steady alarm; cleaning with air resolved problem	Mine visit - in- stall (Sept 24) Monitoring during production	Mine visit (Oct 3)	Mine visit (Nov 15) Fire test demon- strated automatic features Smoke activated one of two sensors			

- (1) Activation for automatic discharge occurred June 13, 1977.
(2) Activation for automatic discharge occurred October 3, 1977.
(3) Activation for automatic discharge occurred October 3, 1977.
(4) Activation for automatic discharge occurred February 14, 1977.

Figure 74 IN-MINE MONITORING SUMMARY, JIM BRIDGER MINE

- The vehicle lighting circuit was found to influence performance of the automatic fire protection system during visits in September and October, both on the ash hauler and on the coal hauler. The problem occurred only when the engine was off and the lights were on. Low voltage caused the fire alarm system lights to illuminate dimly and the system to sound a weak audible alarm. As with the similar occurrences at Diamond Crystal mine, no further action was taken to resolve this intermittent and unpredictable problem because it is apparently minor and non-hazard-producing and occurs only when power is below the design tolerance of the system.
- The power connection of the ash hauler vehicle was modified during October to connect directly to 24-volt DC power at all times rather than routing through the master switch. This procedure has initially eliminated the inductive low voltage from the light circuit as discussed earlier.
- An engine failure occurred 18 August 1977 on the ash hauler, and repair/maintenance of the fire system was limited. Brief inspection of the fire system revealed that the fire control panel was turned off and the cartridge-puncture valve was activated. The seal wire was broken from the manual actuator, indicating inadvertent or accidental manual discharge.
- Illumination of a yellow FAULT light 17 October 1977 on the ash hauler also implied a system discharge because the vehicle had recently been connected to release the extinguishing agent. It was again confirmed, during inspection, because the seal wire was broken, that the manual activation discharge button had been depressed.
- The pressure-leaking Teflon seals of the solenoid valves were replaced with the new urethane seals on the Caterpillar front-end loader during June. These seals continued to hold pressure until the discharge demonstration tests in November.
- A manual activation of the fire protection system on the loader was explained during an August safety meeting when uninformed operators mentioned conducting periodic trial to determine whether or not the system worked. The power switch on the fire control panel includes a momentary-test position that operators are encouraged to use; however, the PUSH-TO-DISCHARGE button on the same panel is active

at all times and should be depressed only in case of a fire. It is sealed with a "tattle-tale" wire that has been found broken on numerous investigations. Adding a hinge guard over the button may relieve the accidental bumping problem. The original manual discharge concept was for a single "push" action on the part of the operator who may already be in a panic situation. Most manual systems must be activated by first pulling a pin which requires three driver actions (i. e., grab, pull, push) rather than one. Field reports indicated panicked drivers don't activate system at all, push the button to activate the system without pulling the pin (thus not activating the system), or pull the pin but do not push the button. It is difficult to predict operator performance during flash fires or panic situations. It would appear that fewer actions and less thought to accomplish a specified goal is desirable but simplicity must be weighed against consequences such as accidental or inadvertent discharges, especially with new or uninformed personnel.

- The ASCO valve solenoid coils on the loader vehicle were replaced twice: once during August after 2 months of installation when they were missing and again during October when they were found with electrically opened circuits. The mine personnel reported they had disconnected power after feeling hot coils.
- Dust caused false alarms in Model 30-40RC smoke detector mounted horizontally over the oil storage area of the dragline during May, June, and August. Clean air purged the sensor and removed the alarm in June. The unit was removed and cleaned, and the electrical box was sealed during subsequent false alarms. It was determined that the circuit boards and optical paths of such detectors should be mounted vertically so as not to collect dust.

The foregoing paragraphs provide several highlights of monitoring the automatic fire protection systems at the Jim Bridger mine. A summary would include the following conclusions:

- Operator and personnel awareness of fire protection systems and consequences of false discharges will result only from proper training and direct association with the new hardware. Except for the low-voltage

interference problem, and one failed control panel in the loader, the electronic circuits of all systems functioned adequately in the mine environment.

- A reliable power supply to maintain proper voltage is very important. The guarded PUSH-TO-DISCHARGE buttons provide protection from accidental bumping but require additional operator thought during critical or panic situations.
- Stored-nitrogen-pressure, dry-powder fire suppression systems can be adequately sealed during the shock and vibration conditions of mine equipment. Repairing and rebuilding such systems is not as convenient as repairing and rebuilding the cartridge systems, but a degree of additional safety is available such as continuous pressure indication and circuit continuity. Additional safety features help to maintain functional fire protection systems, whereas otherwise they may be assembled in error or damaged during production and not be functional.
- Electrical and mechanical maintenance should be performed by several persons cognizant of each system design. In lieu of having several mine personnel knowledgeable and readily available to correct incidental system faults, a local and readily available fire equipment supplier or service agent could be contracted to perform repair functions.

3.8.4 Test Demonstrations

A major contract objective was to conduct discharge tests to demonstrate the automatic features of each fire protection system. This demonstration would allow mine personnel to observe the functional performance of each system onboard the test vehicles. The demonstrations were scheduled at the Jim Bridger mine 8 November 1977 and at Diamond Crystal mine 10 November 1977 (see Appendix I).

Minor schedule changes were necessary because of nonavailability of test vehicles and travel connections.

- Tests at Diamond Crystal mine were conducted on 9 and 10 November 1977, allowing for more repair and possible maintenance than with the original schedule.
- Tests at the Jim Bridger mine were conducted on 15 and 16 November, also to allow more time than the original 1-day plan.

Successful fire demonstrations were conducted on all test vehicles except for the Caterpillar front-end loader at Jim Bridger mine. This vehicle experienced massive pin and joint failures and was undergoing repairs in the shop during the scheduled test week. Fire sensor systems on the other seven vehicles were activated by flame, heat, or smoke from the fire of a diesel-soaked cloth or from smoke candles.

Maintenance was required on four of the seven fire protection systems on the test vehicles prior to the demonstrations. Complete rebuild of the existing manually actuated fire suppression systems which were connected to the automatic sensing systems was required on two vehicles. Three vehicles required maintenance and repair of the fire protection system power supplies. Low or dead batteries existed in two test vehicles, and broken power connections were found on another vehicle.

Except for System I, with the four optical flame sensors and temperature-compensation circuit, the fire alarm response times were greatly affected by the ambient temperature in the fire zone as well as the wind velocity. This problem appears most significant on the surface vehicles on which fires may not be detected because of cold weather and strong crosswinds.

During the underground tests, relatively high ambient temperature (90 to 100^oF) and token air velocity permitted the heat-sensing systems to respond to the flaming torch fire in 8 to 12 seconds. When similar tests were conducted outdoors, where 50-mph wind gusts and lower ambient temperature (40 to 60^oF) existed, the fire alarm response times ranged from 30 to 60 seconds.

3.8.4.1 Diamond Crystal Mine Fire Test Demonstrations

Figure 75 shows several highlights selected from the underground fire demonstration tests at Diamond Crystal mine. Additional information regarding specific vehicle tests follows.

The following persons attended all or part of the underground fire test demonstrations at Diamond Crystal mine:

Richard Siefertman, Mine Manager
Gus Gustafson, Mine Superintendent

Carrol Lopez, Mine Foreman

Ken Bickel, Bureau of Mines Technical Project Officer

Larry Schmeltzer, Bureau of Mines

Dave Johnson, Bureau of Mines

Ralph Stevens, FMC

Mike Cosgrove, FMC.

Vehicle/equipment and model	Type of fire protection system	Repair/maintenance prior to test	Environmental conditions	Test remarks			
				Automatic sensing (audible visual alarm)	Automatic delay prior to discharge	Automatic discharge	Other
Crane Galion 125A	System V (modified) isolated 24 VDC power supply and bypasses master switch	Ansul System repaired and low batteries "jumpered"	Underground, 90°F low R. H. and air velocity, large room near maintenance shop. Fire was diesel rag on stick.	Yes	Yes (10-13 sec)	Yes	Quick alarm (10 sec) and good agent dispersion, yellow FAULT light remained indicating discharged system
Truck Euclid R35	System III (modified) bypasses master switch	None	(same as above)	Yes	Yes (10-13 sec)	Yes	(same as above)
Front-end loader Cat 988	System III	Repaired fuse, valve wire one thermal sensor	(same as above)	Yes	Yes (10-13 sec)	Yes	(same as above)
Cutter Goodnan 2500	System V (modified) bypasses master switch	Replaced bulb, repaired frayed wire, "jumpered" dead batteries	(same as above except temp. was near 100°F at face)	Yes	Yes (10-13 sec)	Yes	(same as above)

Figure 75 IN-MINE DEMONSTRATION SUMMARY, DIAMOND CRYSTAL MINE

3.8.4.1.1 Galion Crane (Figures 76 and 77)



Figure 76 FIRE TEST ON MOBILE CRANE



Figure 77 AUTOMATIC DISCHARGE OF DRY-CHEMICAL FIRE SUPPRESSANT

Inspection of the crane and automatic fire sensing and suppression system revealed that several deficiencies required correction prior to the test. Operating the manual actuator would not release the pin of the cartridge-puncture valve. Also, open pressure lines were observed with the Ansul fire suppression system.

The vehicle had been sitting idle for 6 or 7 days because of a damaged engine. Power was applied to the fire protection system much of this time. Although the circuit tested satisfactorily, when manual discharge (electrically) was attempted, insufficient power was available to release the pin of the cartridge-puncture valve. The battery voltage was only 15.5 volts. Also, several assembly errors were made in the Ansul fire suppression system during repair after the August collision and vehicle damage. The two dry-chemical containers were not interconnected, and one container was empty.

After the low batteries were jumpered with 24-volt DC power, the cylinders were filled with dry chemical, and the residual oil was cleaned from the engine area, a trial test (without discharge) was conducted to determine approximate time to alarm the sensing circuit. The demonstration followed the trial test. The diesel-soaked cloth made a reasonably sized fire, approximately 8 to 10 inches long on the stick with the plume extending 14 to 18 inches high. The fire was positioned near the engine and under the heat sensors. The sensing system observed the heat within 10 seconds and after the designed 10- to 13-second delay, during which time the audible alarm was sounding and the red FIRE light was illuminated, dry-chemical fire suppression agent was automatically discharged. A thick cloud was expelled into the large room as the dry-chemical discharge covered all fire zones in the vehicle very well.

3.8.4.1.2 Euclid Truck (Figures 78 and 79)

The truck vehicle and the fire control system required no maintenance prior to testing, and a successful fire test was performed. The heat source, fire sensor response time, circuit delay, and discharge followed the same sequence as for the crane.

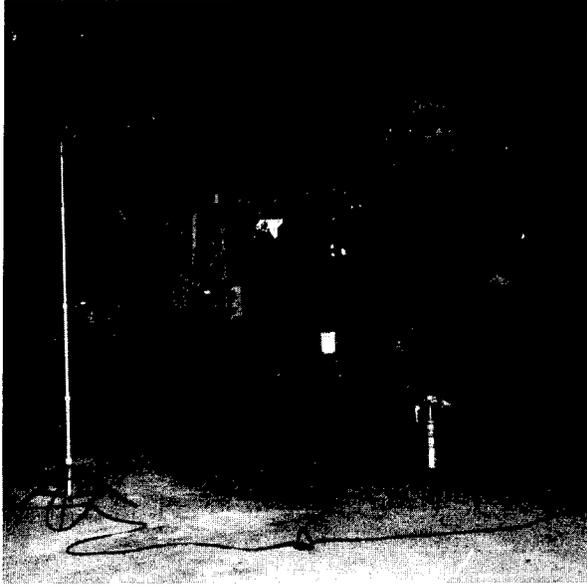


Figure 78 FIRE TEST ON EUCLID TRUCK



Figure 79 START OF DRY-CHEMICAL DISCHARGE ON EUCLID TRUCK

3.8.4.1.3 Goodman Cutter (Figures 80 and 81)

The test crew traveled to the working sections of the mine to test the under-cutter vehicle. Temperature at the lower mine level was near 100°F , approximately 10 degrees hotter than encountered during the other three tests which were conducted at the 1,300-foot level and nearer the intake air shaft.

The fire control panel indicated satisfactory performance when first tested, but, as with the crane, the cartridge-puncture solenoid valve would not discharge when manually activated. A voltage measurement indicated zero voltage across the batteries, indicating the control panel was being powered only by the small charging circuit which was insufficient to power the solenoid valve. Also, a relatively small wire connecting the batteries in series broke easily from corrosion. The spare 24-volt batteries were again used to jumper the dead batteries and allow conduct of the demonstration tests.

Excessive residual grease was cleaned from the cable reel area where a thermal point sensor was located. The torch fire was applied and, after 5 to 10 seconds, the audible/visual FIRE alarm occurred. After the 10- to 13-second fire control system delay, the dry chemical was released automatically.

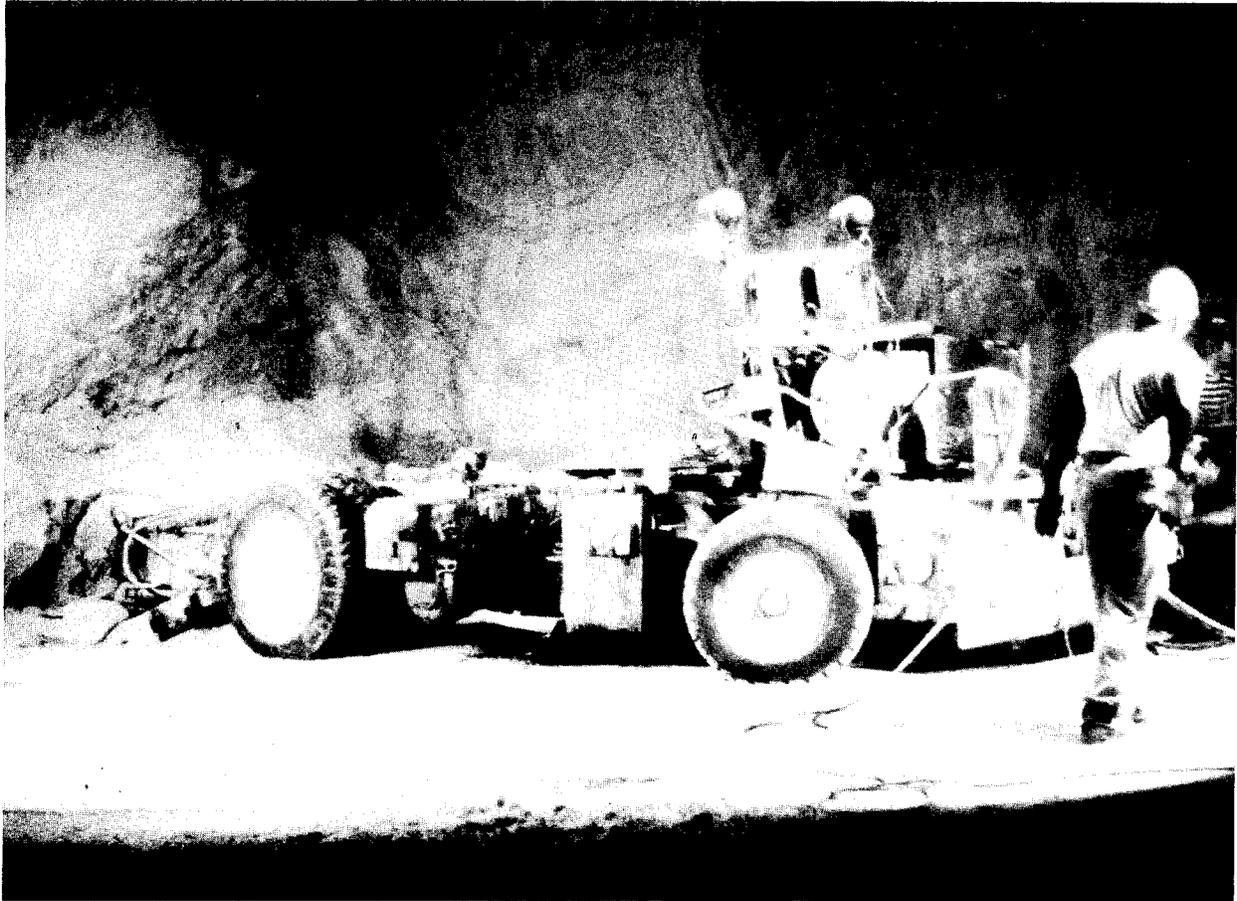


Figure 80 CUTTER AT FACE

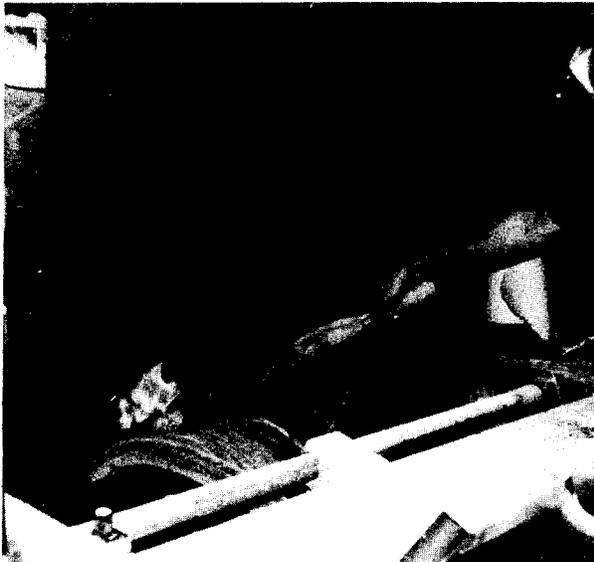


Figure 81 FIRE IN CABLE REEL
AREA ON CUTTER

3.8.4.1.4 Caterpillar Front-End
Loader (Figures 82
and 83)

The loader was fire tested
Thursday, 10 November, after
the other tests were conducted
9 November.

When first inspected, the fire
protection system did not respond
to the 3-second test, indicating
there was no power available.

Broken wires were found at the battery connections and a new fuse and fuse housing were installed. The fire system now tested but resulted in a yellow FAULT light.

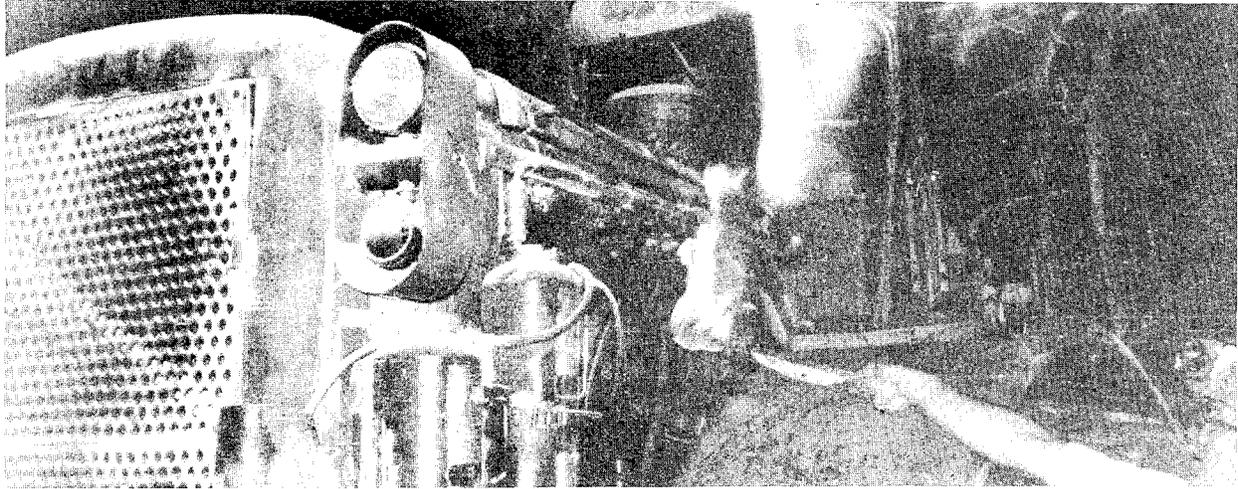


Figure 82 FIRE TEST IN ENGINE AREA



Figure 83 DISCHARGE OF DRY-CHEMICAL SUPPRESSANT

Another test indicated that no voltage was reaching the cartridge-puncture solenoid valve and a power wire was found disconnected from the terminal strip TS2-8 lead for the solenoid valve. Once reconnected, the yellow FAULT light disappeared and only the green POWER light remained after the 3-second test, indicating the fire system was functional. After the left forward thermal-point sensor was replaced for the third time, the fire torch was ignited and the test proceeded as before.

The fire tests were successful in the following respects:

- Sensors responded to the heat stimulus.
- The logic and control system translated the fire signal.
- An audible/visual alarm occurred.
- The cartridge-puncture valve actuated release of a pressurized cartridge to discharge dry-chemical fire suppression agent.

Mine personnel expressed interest in continuing to monitor and test the automatic fire protection systems. Mine personnel, operators, and electricians have become familiar with each of the systems during the 11-month test period and could offer the Bureau and the mine industry additional information about the fire protection systems over a longer period.

3.8.4.2 Jim Bridger Mine Fire Test Demonstrations

The following persons attended all or part of the fire test demonstration at the Jim Bridger Coal Mine:

Jerry Ross, Mine Superintendent

Larry Largent, Mine Safety

Ken Bickel, Bureau of Mines Technical Project Officer

Larry Schmeltzer, Bureau of Mines

Ralph Stevens, FMC

Larry Hall, Becker Fire Equipment Company.

Figure 84 shows several highlights selected from the surface tests. Three of the four automatic fire protection systems installed were tested Tuesday, 15 November 1977. The fourth vehicle was unavailable for fire demonstration because of extensive repairs in the bucket linkage and structure.

Except for the strong, gusty, cold winds and blinding dust which were major deterrents while conducting the outdoor tests, all demonstrations were performed without incident. As with the Diamond Crystal tests, a diesel-soaked cloth on the end of a 3-foot-long stick was the fire stimulus to actuate the sensor systems on the coal hauler and ash hauler. Commercial smoke candles were used to stimulate the photoelectric smoke detectors on the dragline.

Vehicle/equipment and model	Type of fire protection system	Repair/maintenance prior to test	Environmental conditions	Test remarks			
				Automatic sensing (audible visual)	Automatic delay prior to discharge	Automatic discharge	Other
Truck Wabco, 100 ton coal hauler	System I	None (except cleaned optical flame detectors)	30-50 MPM wind gusts, blinding dust, 40-50°F, low RH, test conducted outside in park area, fire was diesel rag on stick	Yes (optical flame detector "saw" flame)	No (instant discharge upon thermal alarm)	Yes	Strong cold wind resulted in 30-45 second delay for thermal alarm. Good agent dispersion, yellow FAULT light remained indicating discharged system.
Truck Wabco ash hauler	System III (modified) bypasses master switch	Prior inadvertent manual discharge required system to be refilled and reset	(same as above)	Yes	Yes (10-13 sec)	Yes	Same as above, except alarm delayed longer (≈ 45-60 sec)
Dragline Marion 8200	System IV	None	High ventilation, minor dust, 50-60°F, low RH, test conducted inside motor room; smoke candles provided stimulus	Yes	N/A	No (Not connected to CO ₂ system)	One of two smoke sensors responded; other (mounted flat) filled with dust and inoperative
Front-end loader Cat 992	System II (modified) bypasses master switch and uses point sensors	Refilled and recharged one cylinder after "partial discharge"	N/A VEHICLE NOT AVAILABLE FOR TEST NOVEMBER 15-16, 1977	N/A	N/A	N/A	N/A

Figure 84 IN-MINE DEMONSTRATION SUMMARY, JIM BRIDGER MINE

Additional details regarding specific vehicle tests follow.

3.8.4.2.1 Wabco Ash Hauler (Figures 85 and 86)



Figure 85 FIRE DEMONSTRATION ON ASH HAULER

The ash hauler vehicle was previously reported as having a yellow FAULT light appearing on the control panel which was confirmed during inspection. The lead seal on the manual pushbutton of the control panel was missing and the wire was broken. Also, the 3-ampere circuit breaker was open, indicating the fire control system was actuated electrically, presumably by accidental manual discharge because of the broken seal wire. The cartridge-puncture

pin of the solenoid valve was down, the pressurized cartridge was punctured, and the Ansul fire extinguishing system had been discharged.



Figure 86 DRY-POWDER CHEMICAL, CLOUD AFTER DISCHARGE

After refilling the Ansul fire suppression system and a successful dry run of the diesel-covered flaming torch actuating the thermal sensing system, the fire demonstration was performed despite extremely high winds and token heat source application of the flaming torch.

After what appeared to be an unusually long time of torch application (approximately 60 seconds), the sensor responded. After the 13-second delay, the extinguishing system was automatically discharged. The dry chemical covered the affected areas well, in spite of the strong crosswinds.

3.8.4.2.2 Wabco Coal Hauler (Figures 87, 88, and 89)

The fire control system on the coal hauler truck was found ON and the system tested properly, indicated by a green POWER light after the 3-second test. The driver expressed no complaints of erroneous operation. After a brief instruction to position the vehicle and clean mud from sensors and nozzles, a mechanic held the flaming, diesel-covered cloth torch to the thermal wire. The optical flame sensor responded immediately to the visible flames; and

after the heat sensor responded (approximately 30 seconds), the automatic discharge occurred without a 13-second delay. The system design provides for instant discharge, if both flame and heat are observed simultaneously. The powder chemical covered the engine, transmission, oil tank, and fuel tank very well despite the strong winds.

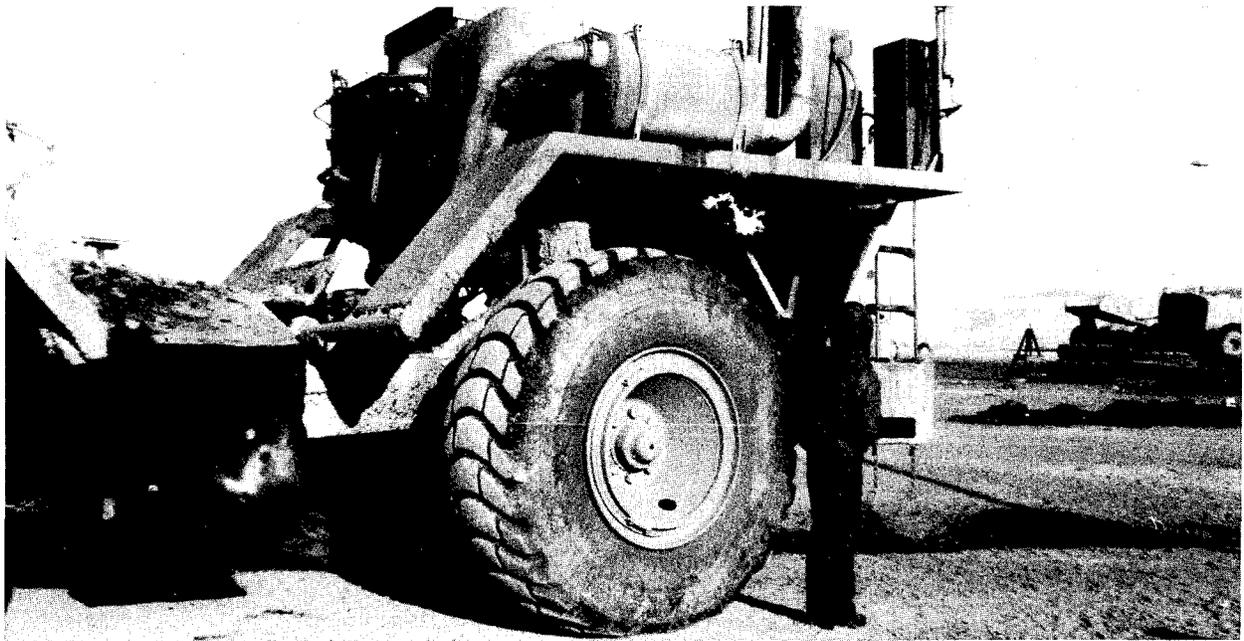


Figure 87 FIRE TORCH IN ENGINE AREA OF COAL HAULER



Figure 88 AUTOMATIC DISCHARGE OF FIRE PROTECTION SYSTEM



Figure 89 DRY-POWDER CHEMICAL CLOUD DISPERSING AFTER DISCHARGE

3. 8. 4. 2. 3 Marion 8200 Dragline (Figures 90 and 91)



Figure 90 SMOKE TEST AT TRANSFORMER AREA OF DRAGLINE

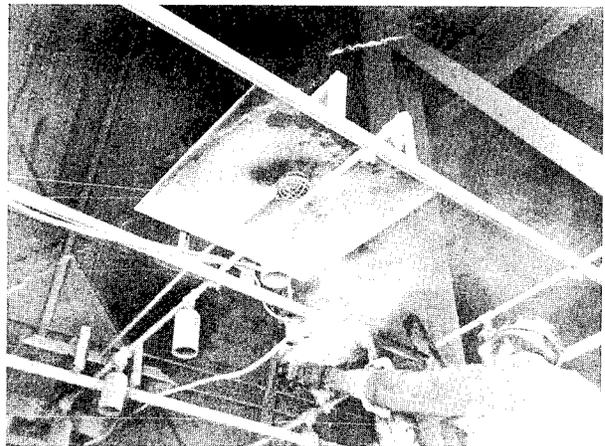


Figure 91 SMOKE TESTS AT OIL STORAGE AREA OF DRAGLINE

The fire control panel in the cab of the dragline tested properly, indicating both smoke sensors were connected and powered (note that the test function does not actually test the LED light source or photocell). The exterior LED on each smoke sensor could not be observed as being illuminated, and the test switch on the smoke sensor over the transformer area did not actuate the alarm. Five smoke candles were used to test the two smoke sensors:

- Two candles in a pan 10 feet away provided no alarm at the transformer sensor, probably because of high ventilation and subsequent dilution.
- One candle in a cup 6 to 8 inches from the sensors produced an alarm at the transformer sensor.
- Two candles in individual cups at a distance of 4 inches produced no alarm from the oil storage sensor.

The smoke sensor over the oil storage area was considered inoperative after large volumes of dense smoke failed to alarm the system, indicating this unit (Model 30-40RC) should be replaced with the same sensor as mounted vertically at the transformer (Model 30-52TC).

As with the outdoor tests, ventilation air in the pressurized interior fire zone was considerable and the smoke did not accumulate for any appreciable duration.

3.8.4.2.4 Front-End Loader

The loader fire control system was reported to have had a partial discharge the previous month. When tested, the yellow FAULT light remained after the normal 3-second test. Both cylinder gages were inspected; the right cylinder read zero and the left cylinder read 500 psi as required.

After recharging and reconnecting (electrically) the valve and pressure gage connectors, the control panel reverted to a green POWER light indicating the fire system was ready for test. Cause for only one cylinder discharging may have been a broken manual operator lever discovered during valve rebuild.

The fire tests on the coal hauler and ash hauler were considered successful, although the lower temperature and strong crosswinds characteristic of the strip-mining operations prevented the relatively small fire stimulus from

providing sufficient heat to quickly activate the heat sensor. By contrast, the optical sensors on the coal hauler (Fire Protection System I) detected the flames immediately and caused an instant alarm. Approximately 30 seconds later, the system performed an automatic discharge. System III (without optics or ambient temperature compensation) on the ash hauler required almost twice as long to detect the fire stimulus of the torch and automatically activate the 13-second delay feature before discharge. These results indicate that in actual production, in cold, windy conditions, a much larger fire is required before heat sensors alone will respond. Integration of ambient temperature compensation (to lower the alarm set point of the thermal sensor) and use of optical flame sensors will improve the fire control system response time and allow the dry chemical to be discharged onto a smaller and more controllable fire.

Once the fire stimulus was detected, the following events occurred:

- Audible/visible alarms were initiated on the control panel in the operator's cab.
- Electrical signals were automatically provided to either of the two solenoid valves on pressurized dry-chemical containers of the coal hauler or to the cartridge-puncture solenoid valve of the ash hauler.
- Effective coverage of dry-chemical extinguishing agent resulted over the affected areas.

Smoke detectors on the dragline performed with only 50 percent effectiveness because one of the two detectors did not respond to the smoke stimulus.

3.9 SUBJECT INVENTIONS

This contract provided for modification of an automatic fire warning and suppression system first developed under U. S. Bureau of Mines Contracts HO122053 and HO232059. Continuous monitor circuits, ambient temperature compensating fire sensors, and fail-safe logic circuits are part of U. S. Patent 3,993,138 issued from the previous work. No subject inventions resulted from USBM Contract HO262052.

Appendix A

PROGRAM PLAN AND SCHEDULE

I. PURPOSE

Development and long-term in-mine testing of several automatic fire protection systems are required to verify the system design, component reliability and performance characteristics in various mining environments.

Prototype hardware of an improved fire protection system was briefly tested under USBM Contracts H0122053 and H0232059, July 1972 - April 1974. Since that time, industry has suggested that an added long-term in-mine evaluation be made and simplified systems be made available that are applicable to the majority of mining equipment.

II. FIRE PROTECTION SYSTEM DESCRIPTIONS

FMC will design, fabricate, and test the following types of systems:

- FMC/USBM SYSTEM I

Existing FMC/USBM system that includes thermal and optical detectors, stored

pressure dry powder filled cylinders, logic control, and ambient temperature compensation.

- FMC/USBM SYSTEM II (Without Optics)

Existing FMC/USBM system without the optical sensors and ambient temperature compensation,

- AUTOMATED MANUAL SYSTEM III

Existing FMC/USBM system without optical sensors or ambient temperature compensation but with new valve concept to adapt to existing manual suppression systems.

- ALARM-ONLY SYSTEM IV

An alarm-only system that includes one or a combination of sensors that provide visual and audible alarm without discharging a fire extinguishing agent.

- AUTOMATED MANUAL SELF-CONTAINED SYSTEM V

A self-contained, battery-operated automatic fire detection system with cost-effective point-source sensors and new valve concept to adapt to existing manual suppression system.

Although dry powder chemical is identified as the extinguishing agent in Systems I and II described above, any of the FMC stored pressure systems can use Halon 1301, CO₂, or other gaseous agents. Engine rooms of drills, shovels, or draglines are examples of areas to use gaseous extinguishing agents.

FMC will also refine previous design efforts to allow rapid vacuum filling of dry powder cylinders.

III. SYSTEM QUANTITIES AND MINE SITES

Three mines have expressed interest in test and evaluation of automatic fire protection systems. Other mines will be contacted for cooperative participation if workable agreements do not materialize with the existing three mines contacted. The proposed systems as they relate to the tentatively selected mine equipment at various mine sites are shown in Table 1.

IV. DESIGN AND TEST SCHEDULE

A total of 12 systems (including spares) will be designed, fabricated, bench-tested, installed on mine equipment, and long-term tested in operating mines. The 20-month program is divided into two phases; a Phase I report concludes and summarizes the first 6-month Design, Fabrication, and Bench-testing. The 12-month Installation and In-Mine

Fire Protection System and Mine Equipment					
Mine Name	I	II	III	IV	V
Mine No. 1 Diamond Crystal Salt Louisiana (Underground)	FMC/USBM	FMC/USBM Without Optics	Automated Manual System	Alarm Only	Self-Contained Automated/ Manual System
Mine No. 2	End Loader	Truck	Truck Crane LHD	Shovel	Electric Cutter
Mine No. 3	Truck	End Loader		Dragline	Truck

Table 1 FMC/USBM AUTOMATIC FIRE PROTECTION SYSTEMS ON MINE EQUIPMENT
USBM CONTRACT H0262052

Validation Test phase concludes with a discharge demonstration. A draft final report is to be submitted within 30 days after completing the discharge demonstrations. An additional 30 days is allowed for USBM approval and FMC publication of the final report. Figure 1 summarizes the proposed schedule.

At the option of the participating mine company and USBM, FMC recommends that the system be allowed to remain on the mine equipment indefinitely for continued use, evaluation, and monitoring by USBM or MESA.

FMC will visit each of the three mines early in the program to select exact mine equipment; identify mounting locations and dimensions; monitor temperature, vibration, and shock conditions; and confirm all test and monitoring contractual arrangements.

Visits will follow FMC bench tests, at which time the systems will be installed on selected equipment.

Two "repair and rebuild" visits are scheduled to each location during the 12-month monitoring period, with another visit scheduled at the conclusion of the program to demonstrate the discharge capabilities of each system. Simulated fire conditions are scheduled to activate the automatic alarm and discharge circuit of the systems.

Color slides and black and white photographs will document both phases of the program and the final demonstration discharge.

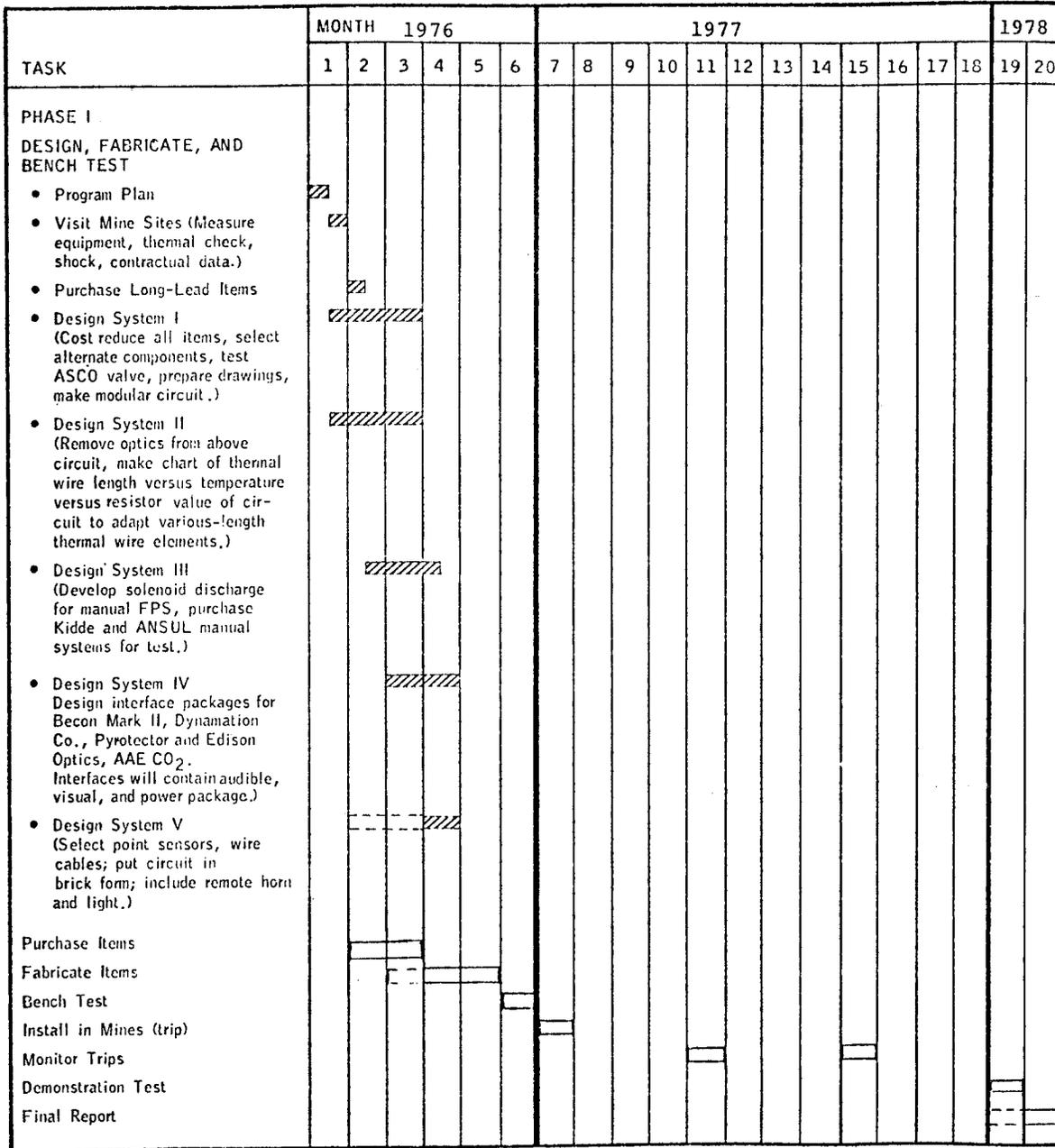


Figure 1 TEST SCHEDULE

Appendix B

REBUILD INSTRUCTIONS FOR STORED-PRESSURE
EXTINGUISHING SYSTEMS I AND II

I. VALVE REBUILD

ASCO Valve GS-HP-X8223-B5
24/DC TPL-9735 or GS-HP-
X8223B5-MO 24/DC TPL-9735
(see also vendor-supplied data
sheet, ASCO Bulletin 8223, Form
V-5580, dated 1972, FMC Drawing
5110262, and Figure 1.

1.1 Valve Disassembly

Starting situation assumed to be
following system discharge or
leak-down when valve is assem-
bled on pressure cylinder.

Certain steps are necessary for
safe removal of the valve from
the cylinder. Secure cylinder in
case of accidental discharge of
pressure and extinguishing agent.
Wear safety glasses at all times
and perform rebuild in ventilated
area. Prior to removal of valve
from cylinder, make absolutely
certain that no pressure exists in
cylinder by opening the main seat
of valve identified as PISTON AS-
SEMBLY. This can be done safely
by operating manual operator(MO)
by turning lever 180 degrees

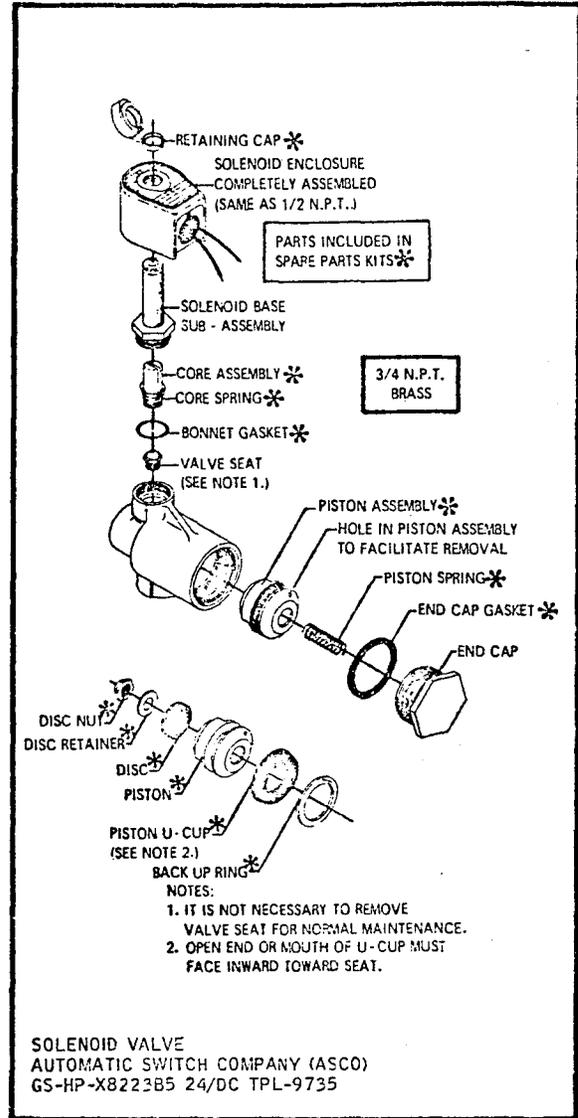


Figure 1 ASCO VALVE ASSEMBLY

clockwise (MO valve only), applying 24-volt DC power to solenoid, or physically pushing the main seal (PISTON ASSEMBLY) off its seat by inserting a tool from the exhaust port. CAUTION Extinguishing agent may discharge; secure cylinder in open, ventilated area and point outlet away. If pressure exists, extinguishing agent left in the cylinder will be expelled rapidly. Do not rely on gages to determine that all pressure has been expelled from the cylinder. (Only trained personnel, knowledgeable of the effects of stored pneumatic pressure and extinguishing agents, should attempt rebuild of the valves). If time permits, another method which allows agent to remain in cylinder and keeps the valve from becoming contaminated is to loosen the 3/4 NPT threads from the siphon tube and cylinder.

1.2 Siphon Tube Removal

Using a 16-inch crescent wrench or equivalent, remove siphon tube (with straight-thread O-ring seal) and valve assembly as a single unit from the cylinder. DO NOT separate the valve body from the siphon tube or the mating threads (3/4 NPT) will be difficult to reseal.

1.3 Disassembly and Component Replacement

Secure valve and siphon tube in vise and completely disassemble the valve and replace all gaskets, O-rings, and seals. Refer to Figure 1 or vendor-supplied data sheet, ASCO Bulletin 8223, for enlarged view of parts.

1.4 Cleaning

Thoroughly clean all powder from valve body, valve parts, and siphon tube. A light dusting is insufficient. Use bristle brushes (tooth brushes) to remove powder from threads, corners, crevices, etc. Use probes (wire or ice pick) to clean ports or other hard-to-reach areas. Use evaporative spray solvent, clean cloth, and compressed air to remove all powder from seals and seats.

1.5 Reassembly

Reassemble valve parts into valve, making certain seats and springs are positioned properly. Tighten all nuts or screws securely.

1.6 Protection

Plug inlet and exhaust ports with protective 3/4-inch plastic plugs and tape

manual operator lever (if equipped) in closed position at 9:00 o'clock (viewed with solenoid above and vertical to valve body and siphon tube) to prevent accidental opening.

II. EXTINGUISHING AGENT (DRY CHEMICAL) MANUAL FILL METHOD

2.1 Valve and Siphon Tube Removal

Valve and siphon tube assembly must be removed from cylinder.

2.2 Weighing

Either (a) separate 25 pounds of dry chemical fire-extinguishing agent (any type) or (b) place cylinder on scale, record empty weight, and add 25-pound weight to determine when sufficient quantity of chemical has entered cylinder.

2.3 Filling

Insert funnel into cylinder neck and pour 25 pounds of powder into funnel, using a standard flour scoop and a screwdriver or rod to vibrate and loosen powder through funnel.

2.4 Sealing

When cylinder is filled with 25 pounds of dry powder chemical, seal neck tightly from humid environments with 1-1/16-12 UNC O-ring plug.

III. POWDER (DRY CHEMICAL) EXTINGUISHING AGENT,
VACUUM FILL METHOD

3.1 Valve and Siphon Tube Assembly

Valve and siphon tube assembly must be removed from cylinder.

3.2 Weighing

Either (a) separate 25 pounds of dry chemical fire-extinguishing agent (any type) or (b) place cylinder on scale, record empty weight, and add 25-pound weight to determine when sufficient quantity of chemical has entered cylinder.

3.3 Filling

Insert bulk filler adapter (with vacuum line attached) over neck of cylinder. Place funnel into adapter and make certain a tight seal is maintained between adapters, cylinder, and funnel. Attach vacuum line to standard household vacuum. Turn on vacuum and scoop powder into funnel to fill cylinder with 25 pounds of powder. Shaking, tapping, or probing powder during vacuum filling will facilitate flow of agent into cylinder. (Electric vibrator attached to supply funnel will aid powder flow.)

3.4 Sealing

When cylinder is filled with 25 pounds of dry powder chemical, seal neck tightly from humid environments with 1-1/16-12 UNC O-ring plug.

IV. INSTALLATION OF SIPHON TUBE ONTO CYLINDER

(Valve may or may not be preassembled in siphon tube)

4.1 General

Assembly of the pressure switch and pressure gage on the siphon tube may or may not be performed prior to assembly of the siphon tube to the cylinder. Caution should be exercised using tools during assembly or damage could occur to the switch and/or the gage.

4.2 Preparation

Remove protection cap(s), plug(s), or tape if installed on cylinder or siphon tube. Apply cup grease to siphon tube O-ring. With hand over cylinder threads, invert cylinder and tap to loosen powder chemical. Turn cylinder upright again and clean powder from neck seat.

4.3 Alignment

With cylinder in VERTICAL position, insert the siphon tube (with clean and greased O-ring attached) into the center of the 1-1/16-12 UNC cylinder neck. Align with center as accurately as possible.

4.4 Filling

Resistance may be noticed as the tube enters into the powder. While straddling the cylinder, and with a gloved hand, apply body weight downward

onto 3/4 NPT threads of siphon tube (or onto solenoid valve if preassembled). Clockwise rotation of the hex portion of the siphon tube will facilitate powder penetration and start of threads.

4.5 Torquing

When the 1-1/16-12 UNC straight threads of siphon tube reach the cylinder neck threads and while still applying pressure, use 14- to 16-inch crescent wrench on siphon tube in clockwise direction to start threads. Torque to bottom out siphon tube onto cylinder. A strap wrench around the cylinder will aid in keeping it from rotating during final torque.

4.6 Sealing

Seal siphon tube tightly from humid environments with a 3/4 NPT cap. Also plug small NPT holes in siphon tube if the pressure gage and switch are not installed. If pressure gage, switch, and valve are already assembled to siphon tube, only the exhaust port need be secured. Keep cylinder vertical; do not place in horizontal position or in any other position that would cause powder to flow upward into the valve.

V. NITROGEN PRESSURIZING

5.1 Pressure

The valve and cylinder containing 25 pounds of dry chemical powder must be filled with 500 psig dry nitrogen (at 70° F). Filling pressures may vary according to Table 1 depending on ambient temperature.

Temperature (°F)	-50	-30	-10	10	30	50	70	90	110
Pressure (psi)	380	400	420	440	460	480	500	520	540

Table 1 FILLING PRESSURE

5.2 Preparation

Make certain the nitrogen supply tank and cylinder to be filled are secured in vertical position and will not tip over. Supply tank should have 1000 psi full-scale gage on supply line side. Purge air hose to remove any dust in line.

5.3 Thread Plug Removal

Remove protective thread plug from exhaust port of solenoid valve and insert Schrader fill valve (Number 798) and adapter (see Drawing 5110262).

5.4 Connections

Attach supply hose (with Schrader fill valve connector Number 2755) to Schrader fill valve stem. Make certain all line connections are secure.

5.5 Valves

Open nitrogen supply valve (NOT REGULATOR VALVE). Supply pressure gage of new supply cylinder will read approximately 3,000 psi. Air hose gage should still show zero. Open Schrader fill valve by turning hex nut counter-clockwise (stem will become shorter).

5.6 Pressurizing

Turn pressure regulator valve stem slowly clockwise (inward) until supply line gage reads approximately 500 psi. Air hose will stiffen and noticeable sound and gage movement on cylinder valve gage will indicate powder-filled cylinder is being pressurized.

5.7 Pressure Balance

When gage on powder-filled cylinder reads 500 psi (or pressure-temperature relationship according to chart), close Schrader fill valve securely and tap solenoid valve body to seat main valve to secure internal pilot and main valves following pressure balance. Close main valve on nitrogen supply cylinder.

5.8 Pressure Bleed

Disconnect Schrader fill valve connector (Number 2755) from Schrader fill valve stem (Number 798). Residual pressure from supply line should leak out quickly.

5.9 Expelling Excess Pressure

The next step is very important because, if performed poorly, powder will enter the solenoid valve cavities and main seat resulting in pressure leaks. Pressure between the main seat of the solenoid valve and the Schrader fill valve (Number 798) must be expelled rapidly so that no powder is pulled up the siphon tube. Place deep socket or vise grips over Schrader fill valve and engage the stem hex nut being careful not to engage the hex on the bottom of valve also. Quickly open Schrader fill valve by turning ratchet vice grips or other speed wrench counterclockwise in a 720-degree continuous motion. The small volume of nitrogen pressure between the solenoid valve main seat and the Schrader fill valve will be expelled and, due to the now existing internal pressure differential in the solenoid pilot valve, the main valve seat will close. Remove the Schrader full valve and adapter.

5.10 Safety Precautions

Insert 3/4 NPT plug into solenoid valve outlet as safety precaution in case of accidental discharge while handling. Apply soap solution over all valve connections and around all threads to check for leaks. Loosen safety plug and fill exhaust cavity of solenoid valve with water to check for leaks. When no leaks occur, blow moisture from solenoid valve, replace safety plug, and mark fill date on tag. Connect tag to neck of cylinder.

Appendix C

CARTRIDGE-PUNCTURE VALVE
TEST RESULTS

Central Engineering Laboratories Santa Clara 758-304-333		MATERIALS LABORATORY TEST REPORT	Lab No: <div style="text-align: right; font-weight: bold;">764855</div>				
C' No: 588-120-000 Date: 8-18-76 Req By: R. Mulder Phone: 3777 Div/Plt: ESD	Part Name: Ansu1 N5L Cartridge Heat No: Size: Mfgr:	Part No: Lot Size: P.O. No: Rec. No: No. Test Pcs:					
Specification: <p style="margin-left: 40px;">obtain pressure to burst diaphragms on vessel versus stroke diaphragm and also gas pressure at end of test. Call Rudy Mulder before testing.</p>							
Information Desired: <table style="width: 100%; border: none;"> <tr> <td style="width: 50%; border: none;"><input type="checkbox"/> Conformance of Material to Specification</td> <td style="width: 50%; border: none;"><input type="checkbox"/> Process Analysis, Bath/Panel Conformance</td> </tr> <tr> <td style="border: none;"><input type="checkbox"/> Conformance of Certification to Specification</td> <td style="border: none;"><input type="checkbox"/> Other — Explain</td> </tr> </table>				<input type="checkbox"/> Conformance of Material to Specification	<input type="checkbox"/> Process Analysis, Bath/Panel Conformance	<input type="checkbox"/> Conformance of Certification to Specification	<input type="checkbox"/> Other — Explain
<input type="checkbox"/> Conformance of Material to Specification	<input type="checkbox"/> Process Analysis, Bath/Panel Conformance						
<input type="checkbox"/> Conformance of Certification to Specification	<input type="checkbox"/> Other — Explain						
Results: 9-10-76							
<p><u>OBJECT:</u></p> <p>Determine the force and displacement required to rupture a diaphragm on gas filled cartridges.</p> <p><u>TEST PROCEDURES:</u></p> <p>The cartridges were tested by mounting them to a pressure gage and placing this assembly in a load frame. A force was then applied to the diaphragm until rupture occurred. Figure 1 shows the test configuration.</p> <p><u>TEST RESULTS:</u></p> <p>Test results are given in Table 1 and force versus displacement plots are given in Figure 2.</p> <p>*Application rate 0.1"/min.</p>							

TABLE I TEST RESULTS

<u>TEST #</u>	<u>GAS</u>	<u>CARTRIDGE RATING (lbs.)</u>	<u>MAXIMUM FORCE (lbs.)</u>	<u>PRESSURE*(psig)</u>
1	Nitrogen	900	61.4	200 **
2	Nitrogen	900	63.0	1,220
3	CO ₂	1,800	87	850

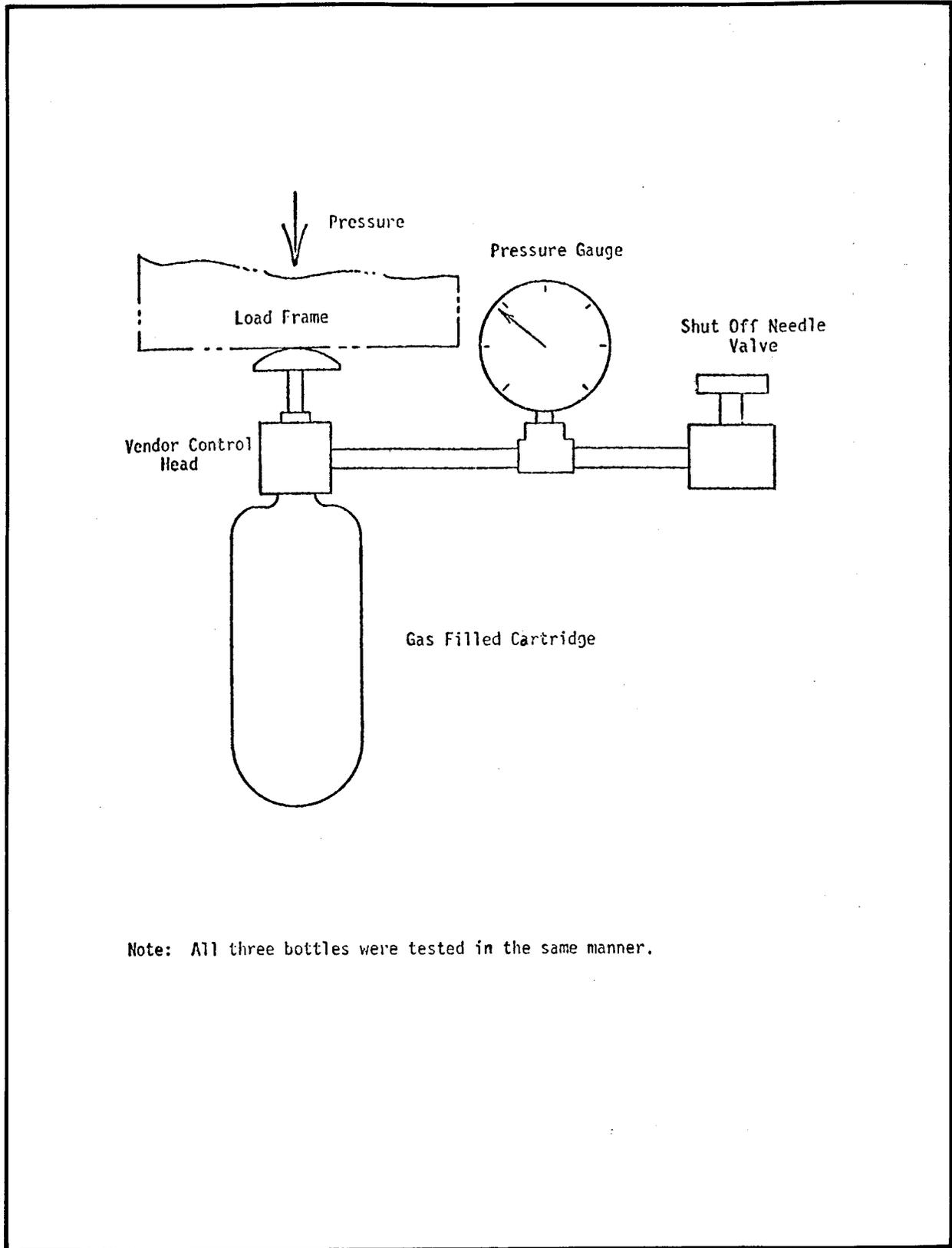
*Readings taken at conclusion of each test.

**Readings taken after pressure was released.



Rick Brown

rb



Note: All three bottles were tested in the same manner.

Figure 1 DIAPHRAGM RUPTURE TEST SETUP

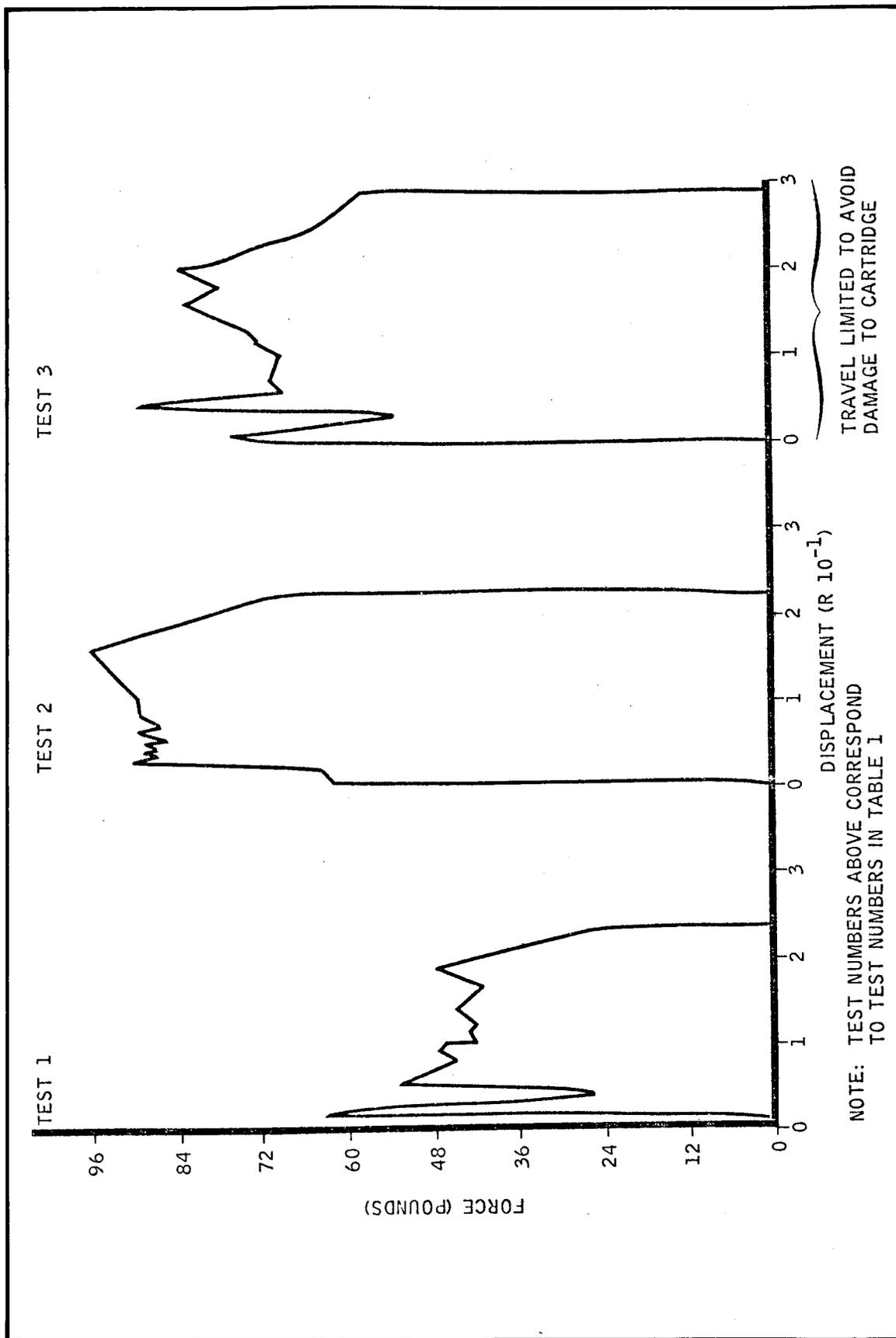


Figure 2 FORCE VERSUS DISPLACEMENT

FMC Engineered Systems Division
Santa Clara

Interoffice

To R. Stevens
Date October 29, 1976

From J. Mantel
cc M. Cosgrove

Subject SHOP TEST OF ANSUL PRESSURIZED
CARTRIDGE WITH DIAPHRAGM RUPTURING
MECHANISM TEST DATE: OCT 20, 1976

Object: To determine if certain energy levels would rupture the diaphragm sufficiently for gas release.

Test Set-up: Attached sketch SK102076JRM (Photos also available in file)

#1 TEST

Ansul Cartridge (#4 or #5) with General manufacturing seals - 10. oz's (wgt) CO₂ gas

Total weight of cartridge and plunger mechanism = 1.283 lb

DROP DISTANCE

<u>Feet</u>	<u>Inches</u>	<u>KE-lb. ft.</u>	<u>Remarks</u>
.779'	9.35"	1.0	Cylinder diaphragm cleanly ruptured - both drops
1.559'	18.7	2.0	

#2 TEST

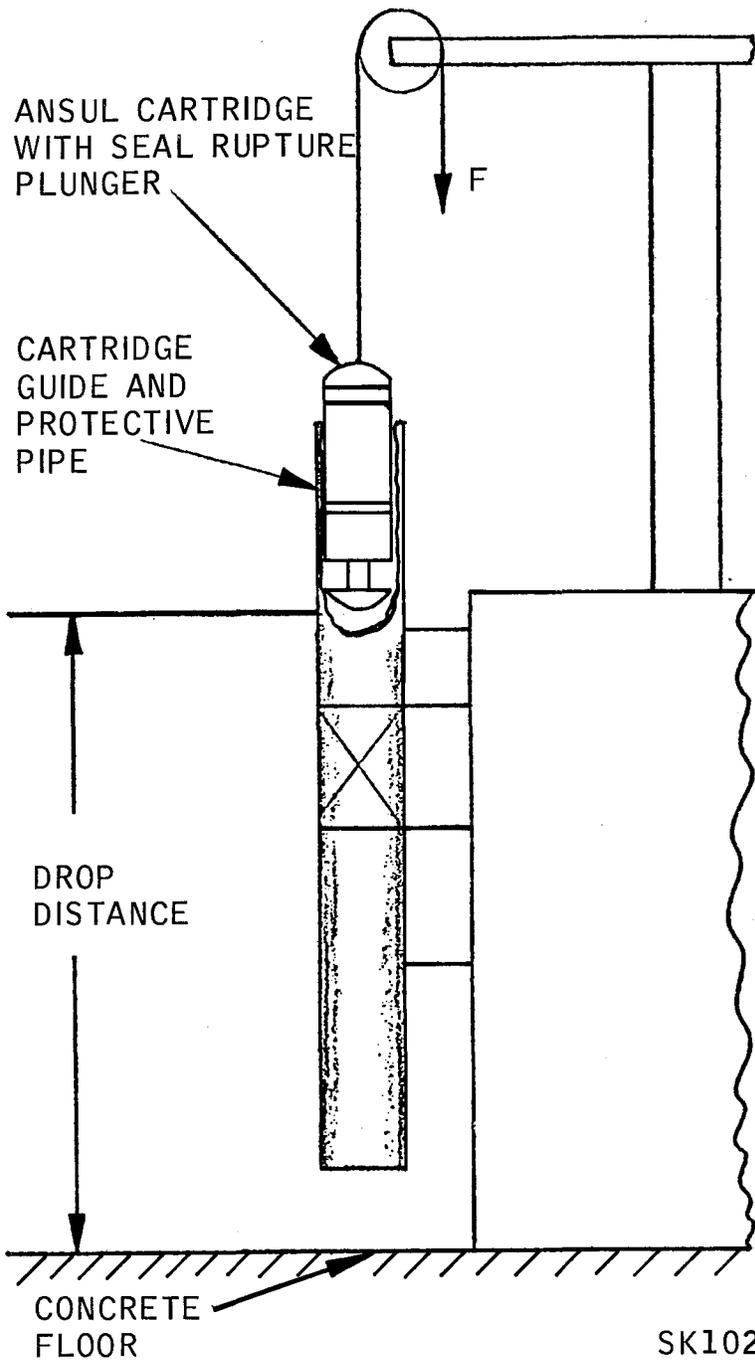
Ansul Cartridge (NSL) - 21.75 oz's (wgt) N₂ gas

DROP DISTANCE

<u>Feet</u>	<u>Inches</u>	<u>KE-lb. ft.</u>	<u>Remarks</u>
.667	8	1.35	Full circle penetration occurred but, exiting gas sound led the writer to suspect limited depth penetration only.

As a result of these tests, and including a reasonable factor of safety, the design goal for the plunger spring mechanism should be approximately 1.75-2.25 lb.-ft.

Jack Mantel
Jack Mantel



ANSUL CARTRIDGE
WITH SEAL RUPTURE
PLUNGER

CARTRIDGE
GUIDE AND
PROTECTIVE
PIPE

DROP
DISTANCE

CONCRETE
FLOOR

F

SK102076JRM

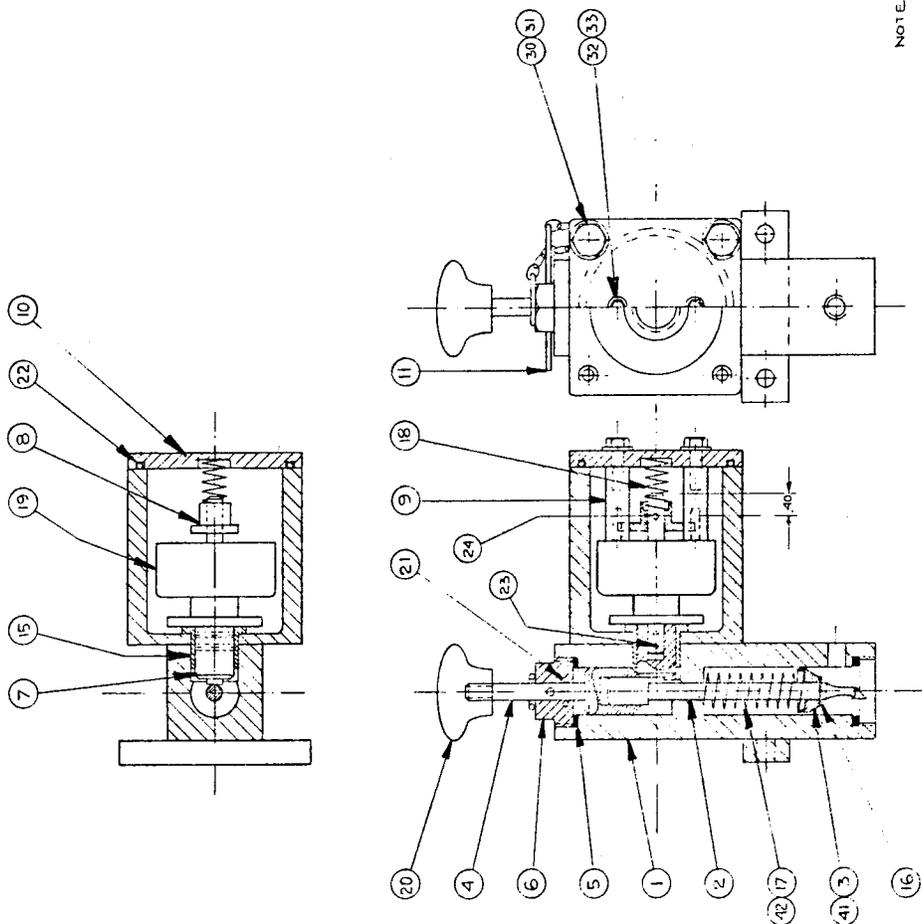
TEST SETUP TO DETERMINE
ENERGY TO RUPTURE CARTRIDGE SEAL

ITEM NO.	PART NUMBER	QTY	DESCRIPTION
1	513012	1	HOUSING ELEMENT
2	513013	1	PISTON PIN
3	513014	1	SPRING SEAT
4	513015	1	PUNGER
5	513016	2	SEAL
6	513017	1	PLUG
7	513018	1	TRIGGER
8	513019	1	SLIDE
9	513020	2	STUD
10	513021	1	COVER
11	513022	1	SAFETY PIN ASSEM

- REF. 15 FB-02-B | BEARING
 16 513025 | WASHER, PRECISION SUPPORT
 17 1/8" x 3/16" | DIE SPRING, MEDIUM DUTY 0.052 DIA
 18 1/8" x 3/16" | COMP. SPRING 1/2 FREE
 19 1/8" x 3/16" | WASHER
 20 1/4" x 5/16" | WASHER, PLASTIC WITH
 21 2.010 | O-RING
 22 2-036 | O-RING
 23 2.010 | O-RING
 24 1/4" x 3/16" | WASHER, PLASTIC WITH

- SEE NOTE 23
 SEE NOTE 24
- 30 4 WASHER, LOCK
 31 1/4" x 5/16" | UNF
 32 1/4" x 5/16" | UNF
 33 2 PER BOLT 5/16-28 UNF 3/8 LONG STEEL CHD. PL.

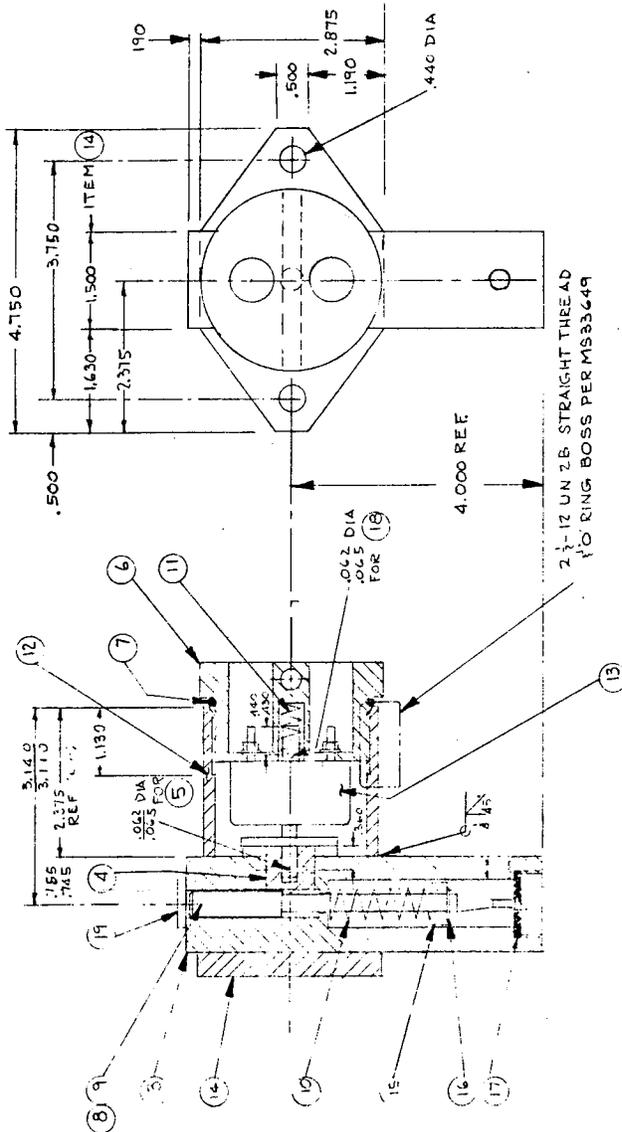
- 41 B 513033 | SPRING SEAT
 42 1/4" x 3/16" | DIE SPRING, MEDIUM DUTY 0.052 DIA.



NOTE: PIN AT ASSEM ITEM 7 - B-19
 CARING OFF TO DIA

Reproduced from
 best available copy.

Figure D-2 PROTOTYPE VALVE A/M GAS CYLINDER (FMC Drawing 5130111)



ITEM	QTY	DESCRIPTION	STOCK	MATERIAL
1	1	VALVE ASSY		
2	1	WELDMENT		
3	1	VALVE BODY		
4	1	TRIPPER		
5	1	ROLL PIN		
6	1	PLUG		
7	1	O-RING		
8	1	PLUNGER		
9	1	SPRING		
10	1	TUBING		
11	1	SOLENOID-LEVER		
12	1	MTG. PLATE		
13	1	WASHER-CD		
14	1	WASHER-CD		
15	1	WASHER-CD		
16	1	GASKET		
17	1	ROLL PIN		
18	1	CAP		
19	1			

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Figure D-3 SOLENOID VALVE GAS CYLINDER ACTUATOR (FMC Drawing 5130226)

Appendix E

VENDOR INFORMATION, SENSORS

The Sentinel[®] SMOKE DETECTOR

3040RC - 3041RC SERIES

INSTALLATION INSTRUCTIONS

103-40



GENERAL

The Sentinel 3040RC Series Smoke Detectors, Models 3040RC and 3041RC, are rate compensated fixed sensitivity devices designed for connection to any manufacturers listed compatible control unit. The 3040RC models are also equipped with a 135° F heat detector. All models are also suitable for releasing device service.

The detector will respond when smoke in the chamber reaches the fixed sensitivity setting, typically 1.5% per foot, or when smoke increase within the chamber exceeds a predetermined rate - between 0.05% to 0.1% per foot per minute.

The detection chamber of the Sentinel is a labyrinth assembly which permits free access of smoke. A light beam from an LED (light emitting diode) with a 40 year rated life is projected across the chamber into a light catcher.

A recessed photosensing device with associated optics is located perpendicular to the light beam and it sees no light in the "no smoke" condition. Smoke particles entering the chamber cause light from the light beam to scatter on to the photosensing device, decreasing its resistance, and providing voltage for amplification to the "alarm signal" level.

SYSTEM CONNECTION

NOTE

DETECTOR OPERATING VOLTAGE RANGE MUST MATCH POWER SUPPLY OUTPUT VOLTAGE.

Each detector contains one set of Form A (SPST) alarm contacts for connection to the alarm initiating circuit, and two sets of Form C (DPDT) alarm contacts for annunciation, door holder/release service, fan shut down elevator by-pass, etc.

The detector locks in on alarm and has a lock in alarm/trouble light (LED) on the outer surface of the housing which illuminates in the event of alarm or trouble signal. Detector reset is achieved by momentarily interrupting power to the detector. Supervision of power is necessary and is accomplished by installing an End of Line Relay Assembly 2040 or its equivalent. The E.O.L. Relay Assembly contacts are closed when energized and are wired in series with the alarm loop. Power failure or a break in the power loop deenergizes the E.O.L. Assembly causing the relay contacts to open. This results in a trouble signal at the control panel.

5004-30A

LOCATION

The 3040RC Series should be mounted on the ceiling not less than 6 inches from a side wall. Exact detector location shall be determined by an evaluation based on engineering judgement supplemented if possible, by field tests. For additional information on detector location and spacing, contact the National Fire Protection Association, 470 Atlantic Avenue, Boston, Mass., 02210, and request a copy of NFPA No. 72E, the Standard on Automatic Fire Detectors.

INSTALLATION

The detector is provided with a separate steel mounting plate which attaches to standard 4 inch square or octagonal electrical boxes, with box size as required by the National Electrical Code for the number and size of conductors used. A prewired plug-in connector attached to and protruding through the mounting plate affords easy connection to system wiring.

To mount:

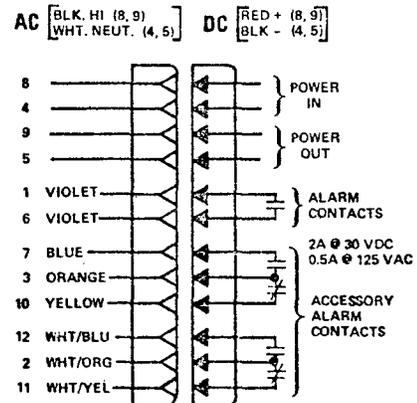
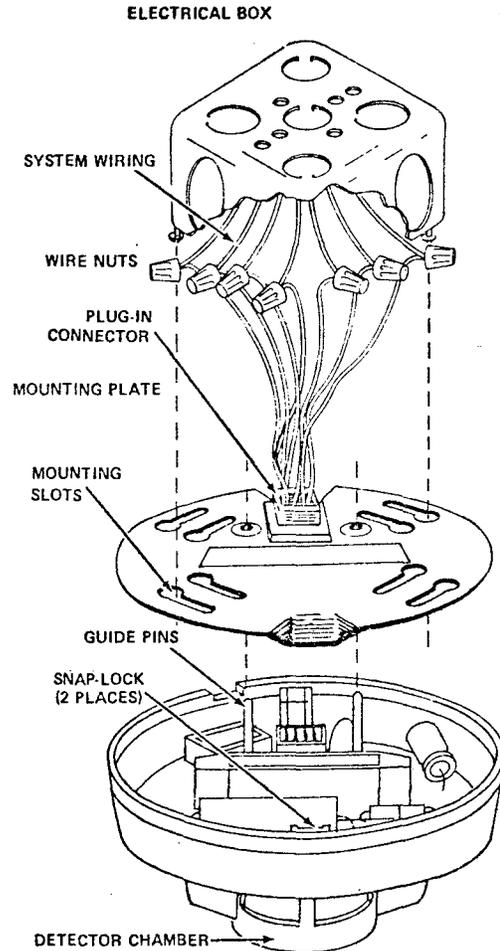
- Connect pigtails from mounting plate connector to system wiring observing the color code shown in Figure 4.
- Loosen, but do not remove the electrical box screws.
- Attach the mounting plate to the electrical box by engaging the appropriate keyslots in the mounting screws. Turn the plate clockwise to achieve the desired detector orientation and tighten the mounting screws.
- Attach the detector to the mounting plate by inserting the guide pins into the holes on the mounting plate. Press the detector so that the snap lock feature fastens the detector to the mounting plate.

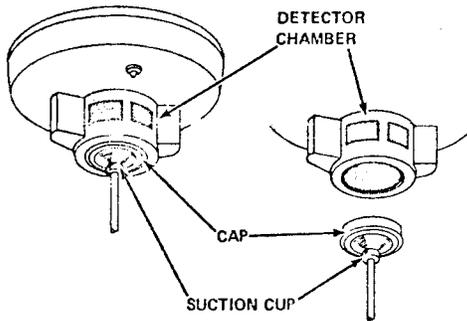
To Remove:

- Insert a screwdriver 1/2 inch into the slot on the side of the detector housing and turn or pry down. This will disengage the snaplock and the male and female ends of the connector. Removal instructions are indicated on the face of the detector.

TESTING

The 3040RC Series has a built in test feature so each unit can be functionally tested without generating smoke. Applying a magnet to the area of the alarm/





DETECTOR CAP REMOVAL

ELECTRICAL SPECIFICATIONS

Model	3040RC-6	3040RC-12	3040RC-24	3040RC-120
Voltage	6-9VDC	12-16VDC	22-27VDC	120VAC
Typical Current @ 25°C	.005A	.005A	.005A	.035A
Start Up Current (Approx. 2 min.)	.025A	.025A	.025A	.035A
Current, Alarm	.085A	.050A	.035A	.035A
Current, EOL Relay Assembly	.060A	.035A	.025A	.010A
Contact Rating:				
All smoke detectors: 2A, 30VDC, 0.5A; 125VAC				
EOL assembly: 1A, 30VDC, 0.5A; 125VAC				
Dimensions:				
All smoke detectors: 6" dia. x 2 1/4" deep				
EOL assembly: 3/4" x 1 1/4" x 1 1/4"				

MODELS AVAILABLE

Part No.	Description	Voltage
3040RC	Smoke detector with 135°F heat detector	Specify 6, 12, 24VDC or 120VAC
3041RC	Smoke detector without heat detector	Specify 6, 12, 24VDC or 120VAC
20-40	End-of-Line Relay Assembly	Specify 6, 12, 24VDC or 120VAC
11-1188	Separate baseplate for all 3040RC detectors	All
20-3391	Jumper plug for use with pre-wired baseplate to verify system wiring	All

trouble light will operate a reed switch which illuminates a test LED within the unit's optical enclosure. Illumination of the test LED reflects light onto the smoke cell duplicating the condition which occurs when smoke enters the detection chamber.

MAINTENANCE

While no regularly scheduled maintenance is necessary, periodic cleaning of the detection chamber may be required when detectors are located in abnormally dirty or dusty environments.

CAUTION

DISCONNECT POWER TO THE UNIT BEFORE CLEANING.

The plastic cap on the external end of the detection chamber snaps out and may be removed with a suction cup allowing full access to all parts of the detection chamber. A low pressure air line may be used to blow out the detection chamber.

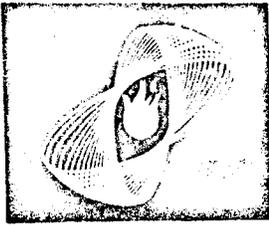
NOTE

The smoke detection photocell normally sits in darkness. When the chamber cap is removed for cleaning, the photocell is exposed to light. Photocells undergo a temporary shift in characteristic when exposed to high light levels. Because photocells have a "memory", the detector should be allowed to recover for about 30 minutes after cap replacement before the unit is repowered.

In the event a detector needs to be temporarily removed from the system, normal system operation may be continued by using jumper plug 20-3391 to complete the power loop and maintain the normally closed accessory alarm contacts at the particular detector location.

SPECIAL CONSIDERATIONS

- The 3040RC Series light source is an LED with a rated 40 year life. Detectors should be returned to supplier if service is required.
- Start up current consumption of each detector should be considered when planning power supply requirements.
- Do not install detectors in areas where ambient temperatures will exceed 100°F.



PYROTECTOR INCORPORATED

333 LINCOLN ST., HINGHAM, MASS. 02043

TEL 617 749 3466
TWX 710 348 0163

SMOKE DETECTORS SMOKE/HEAT DETECTORS 30-52 SERIES

Bulletin 52/53

NEW LED A.C. POWERED SMOKE DETECTOR by PYROTECTOR



U.L. LISTED — UL 168
FIRE TESTS IN ACCORDANCE
WITH UL 167

COMPLIES WITH LATEST
BUILDING CODES & STANDARDS

5 YEAR WARRANTY

GENERAL

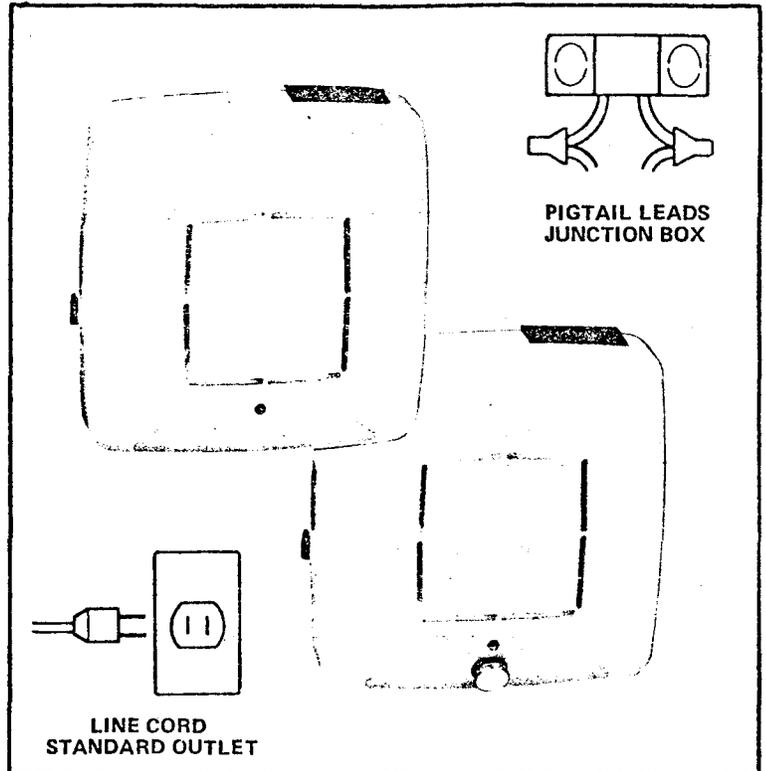
Pyrotec's new Photoelectric Smoke Sentinel Smoke Detectors are highly sensitive, self-contained devices designed to operate from ordinary household power, 120VAC. The Sentinel utilizes solid state components and an LED Light Source for extra long life. The LED is fully regulated. They alarm when smoke entering the detector reaches obscuration of less than 1% per foot.

The Pyrotec Smoke Sentinel Smoke Detector is available for wall or ceiling mounting.

The 30-52 series detectors are equipped with pigtails and a quick disconnect plug for mounting directly to any standard electrical box.

The 30-53 series detectors are equipped with a nine foot line cord for plugging into a regular household receptacle.

See MODELS AVAILABLE chart for many variations of both the 30-52 and 30-53 series Smoke Sentinel Detector.



MODELS AVAILABLE 30-52 Series

- 30-52 Photoelectric Smoke Detection.
- 30-52T Photoelectric Smoke Detection and supplementary 135°F. thermal.
- 30-52TC Photoelectric Smoke Detection and supplementary 135°F. thermal — plus external contacts for remote alarm switching.
- 30-52M Photoelectric Smoke Detection with "Tandem" Circuit allowing interconnection of up to six detectors.
- 30-52TM Photoelectric Smoke Detection and supplementary 135°F. thermal — with "Tandem" Circuit allowing interconnection of up to six detectors.
- 30-52TCM Photoelectric Smoke Detection and supplementary 135°F. thermal — with "Tandem" Circuit allowing interconnection of up to six detectors — plus external contacts for remote alarm switching.

30-53 Series

- 30-53 Photoelectric Smoke Detection.
- 30-53T Photoelectric Smoke Detection and supplementary 135°F. thermal.
- 30-53TC Photoelectric Smoke Detection and supplementary 135°F. thermal – plus external contacts for remote alarm switching.

OPERATION

The Smoke Sentinel Smoke Detector maintains a constant vigil in the area of installation and instantly sounds an alarm when smoke entering the detector reaches obscuration of less than 1% per foot. The Pyrotector Smoke Sentinel approach to smoke detection involves the use of a light-tight enclosure (Smoke Chamber) which is open to the atmosphere. A regulated amount of light (LED) is purposely introduced into the darkened chamber and focused to form a sharp beam. Smoke particles entering the Smoke Chamber cause part of the light beam to reflect onto the surface of a photoelectric cell. Exposure of the cell to this reflected light causes its resistance to decrease appreciably, resulting in an alarm condition. The circuit includes a regulating photocell that continuously monitors the LED intensity and adjusts it as necessary to compensate for possible variation caused by film, temperature, or age.

Models 30-52T, 30-52TC, 30-52TM, 30-52TCM, 30-53T, 30-53TC are fitted with a thermal switch which is activated when ambient heat reaches 135°F. and also triggers the detector.

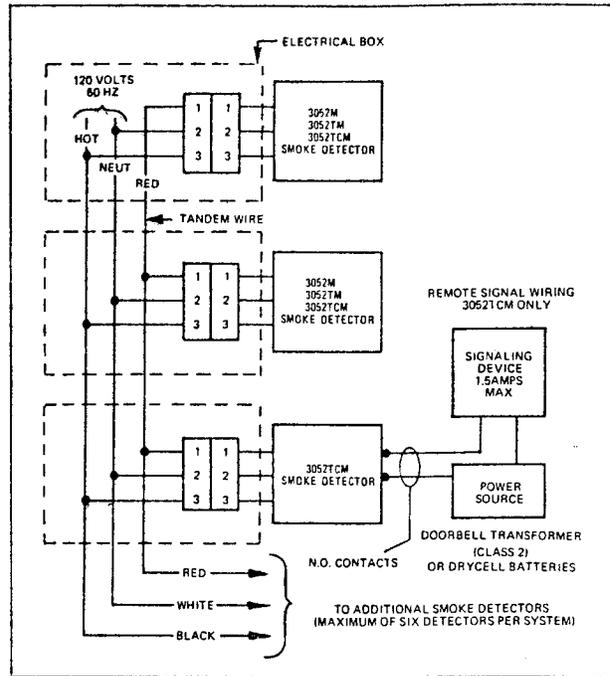
Each model is equipped with an alarm horn which operates when the detector goes into an alarm condition. Horn loudness is 85 dBA at a minimum of 10 feet. Each model is also equipped with an externally operated test switch which simulates the action of reflected light from the LED when smoke is present in the chamber. The test switch activator is located on the side of the detector allowing external operation. In addition, Models 30-52TC, 30-52TCM, and 30-53TC have an alarm relay for triggering remote alarm signaling devices.

INSTALLATION

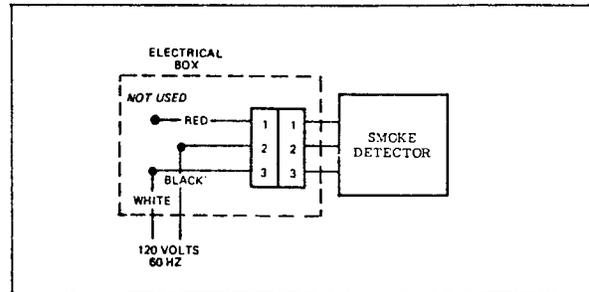
The Smoke Sentinel Detectors are designed for mounting on ceilings or walls. They should be located in hallways or areas adjacent to bedrooms so that fire can be detected before it reaches sleeping persons.

SPECIFICATIONS

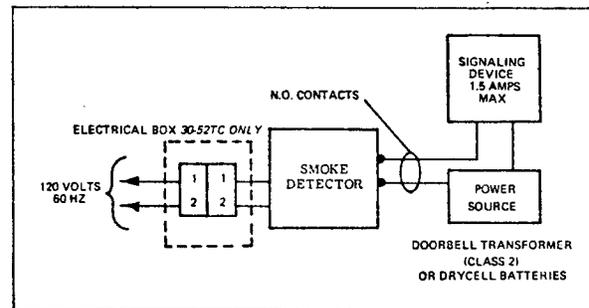
Input Voltage	120VAC
Input Current	0.08 Amperes
LED Life	Approx. 40 years
Optical Density0034 per ft.
Smoke Obscuration	0.77% per ft. max.
Thermal Detector	135°F.
Horn Loudness	85 dbA @ 10 ft.
Remote Signal Contacts	1.5A @ 30 VDC



**TANDEM WIRING DIAGRAM
MODELS 30-52M, 30-52TM, 30-52TCM ONLY**



**SINGLE DETECTOR WIRING
MODELS 30-52M, 30-52TM & 30-52TCM**



**WIRING DIAGRAM
MODELS 30-52TC & 30-53TC**



**PYROTECTOR
INCORPORATED**

333 Lincoln Street — Hingham, Massachusetts 02043
Phone 617/749-3466

Distributor

1.3 FLAME DETECTOR, P/N 30-2013-5

The Flame Detector, Figure 1-1, is an optical sensing device which utilizes a hermetically sealed balanced photocell calibrated to produce an alarm output when the correct balance of infrared and ultra-violet radiation of flame is intercepted. Normal output voltage of the detector is approximately 3.5 volts increasing to approximately 14 volts when in alarm state.

The detector is encapsulated within a black anodized housing with a viewing cap of high temperature, shock absorbing glass. Electrical interface is provided by an MS3101R-16S-8P electrical connector.

Dimensions	2.40 in. x 1.25 HEX
Mounting	Single Hole 1.06 In. Dia.
Weight	2 1/4 oz. Max.
Power Requirements	21 to 32 VDC
Mating Electrical Connector.	MS-3106R-16S-8S

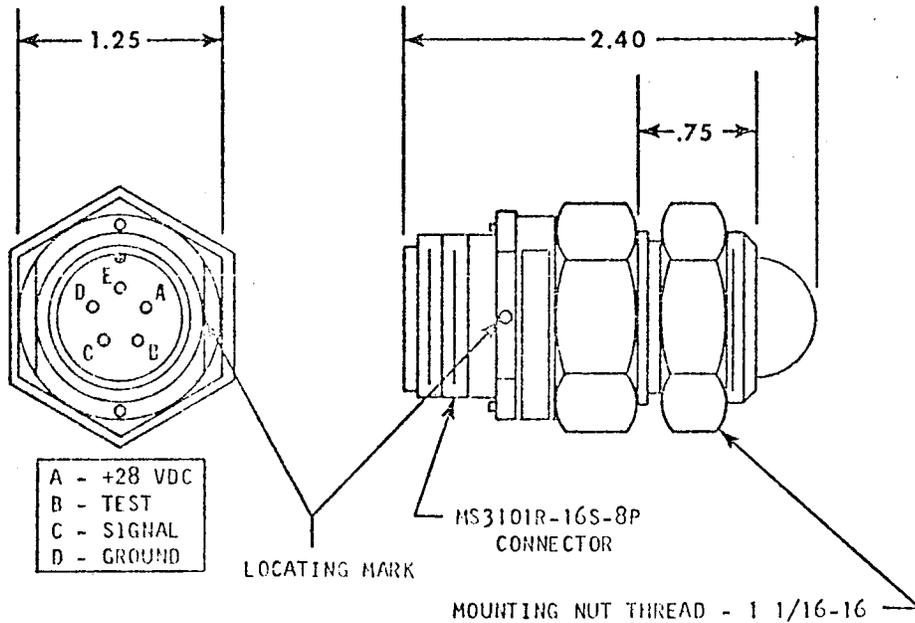


Figure 1-1. Flame Detector, 30-2013-5

ORIGINAL

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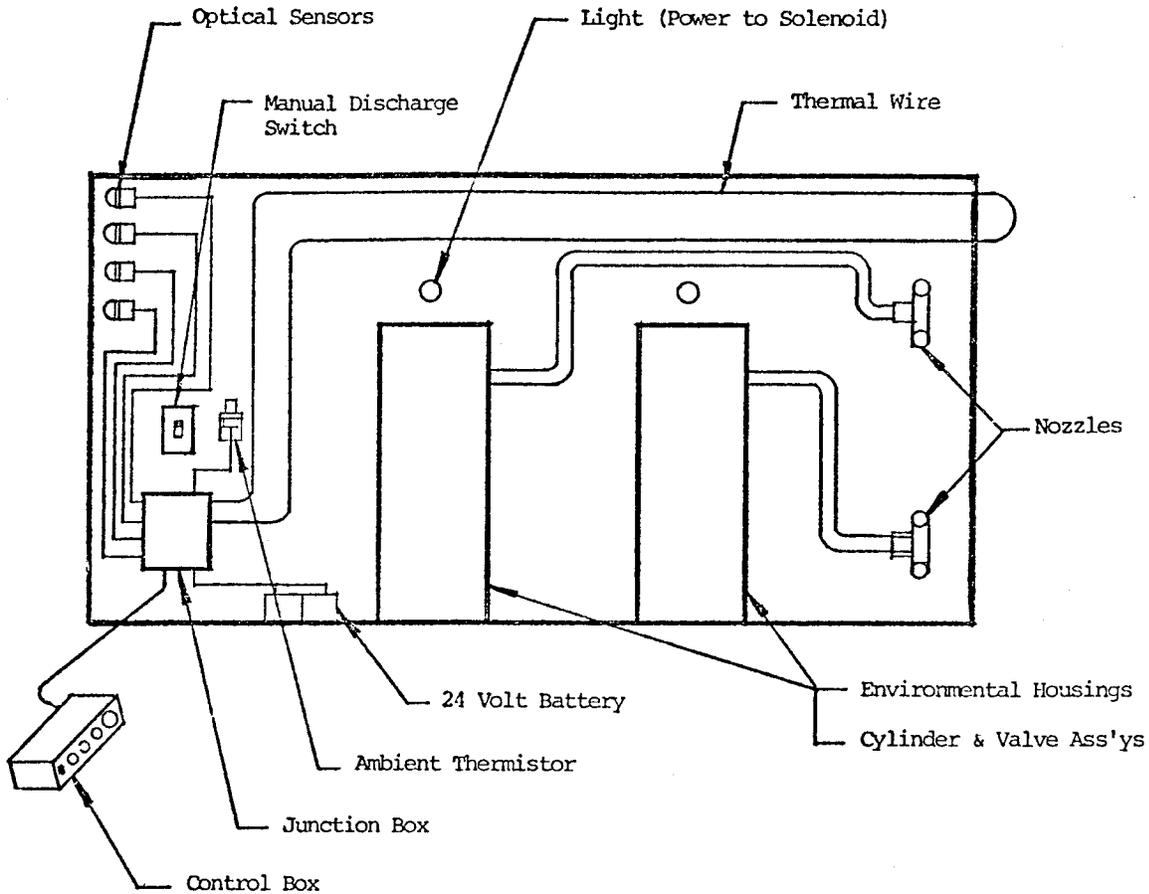
Appendix F

DEMONSTRATION TEST AGENDA

<u>TIME</u>	<u>EVENT</u>	<u>LOCATION AND COMMENTS</u>
8:15 - 9:45 AM	Introduction and Conference: Contract review and status report. Slides of mine equipment will be shown as well drawings and artists sketches of hardware and general arrangements of hardware on vehicles. HANDOUTS of drawings and sketches provided to USBM.	G.O. Conference Room - Movie and slide projectors required.
9:45 - 10:30 AM	Tour thru ESD shop and electronics lab: evaluation of film sequences	Contract hardware manufacturing and assembly will be observed.
10:30 - 11:30 AM	Initial USBM filming of hardware manufacture, assembly and test set-up.	Various shop work stations will be filmed.
11:45 - 1:15 PM	LUNCH	
1:30 - 2:30 PM	Demonstration Test "A" Six static tests and one dynamic test (discharge) will describe FMC/FPS systems I and II.	Test location of S. E. corner of ESD property (near fence) (FMC photographer required)
2:30 - 3:30 PM	Demonstration Test "B" Four static tests and one dynamic test (discharge) will describe FMC/FPS systems III and V.	Test location of S. E. corner of ESD property (near fence) (FMC photographer required)
3:30 - 4:30 PM	Demonstration Test "C" Two static tests will describe FMC/FPS system IV	Test location of S. E. corner of ESD property (near fence) (FMC photographer required)

DEMONSTRATION A

(System I and II)



STATIC TEST

(Use Solenoid Light - No Discharge)

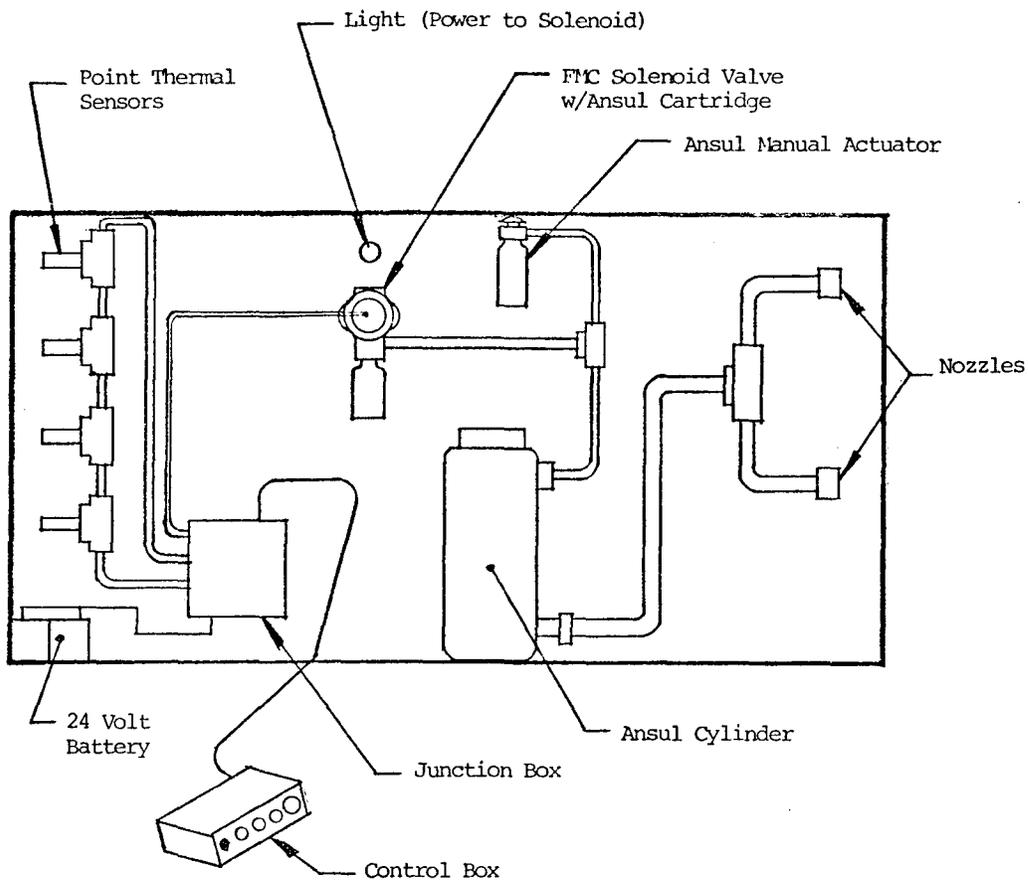
- (1) Power on and Test/Reset
- (2) Manual Discharge (Control Box)
- (3) Manual Discharge (Remote)
- (4) Flame Detector Only
- (5) Heat Detector Only
- (6) Fault Indicator

DYNAMIC TEST - AUTO DISCHARGE

- (1) Power on and Test/Reset
- (2) Simulate Thermal Wire and Optical Sensors with Blow Torch
- (3) Result; Optics Alarm, Auto Discharge Occurs After Wire Reaches 270°F
- (4) Fault Light Appears Indicating Pressure Loss

DEMONSTRATION B

(System III and V)



STATIC TEST

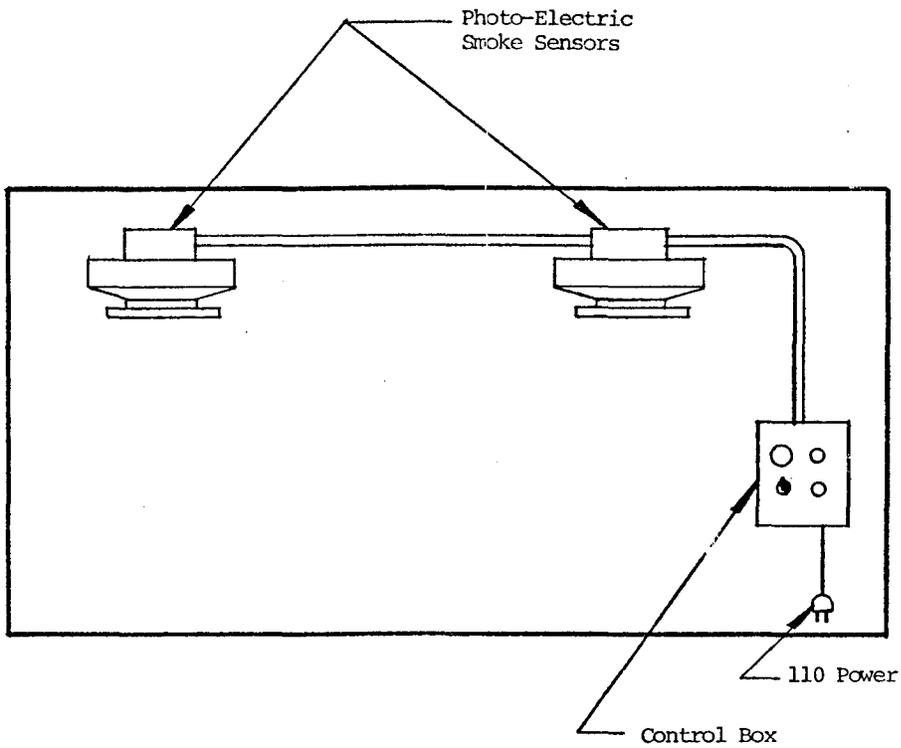
- (1) Power on and Test/Reset
- (2) Manual Discharge
- (3) Fault Indication (Break in Wire)
- (4) Heat Detector

DYNAMIC TEST

- (1) Power on/Reset
- (2) Stimulate Heat Sensor With Blow Torch
- (3) System Automatically Discharges After 13 Second Delay Period
- (4) Fault Light Appears Indicating Discharged System

DEMONSTRATION C

(System IV)



STATIC TEST

- (1) Power on and Test
- (2) Stimulate With Smoke to Alarm Sensor. Purge to Clear Sensor

Appendix G

REPORT OF FIRE ON TEST VEHICLE

FMC Engineered Systems Division
Santa Clara

Interoffice

To File

Date September 8, 1977

From Ralph B. Stevens

cc A. Escover
R. Abbe

Subject FIRE ON TEST VEHICLE AT
DIAMOND CRYSTAL MINE

During third shift, 9/2/77, at approximately 4:30-5:00 AM, an accidental fire occurred on the Euclid R-35 truck operating in Diamond Crystal mine. The truck was equipped with an FMC/USBM system III automatic fire protection systems that was coupled to an Ansul fire suppression system. The fire was caused by a shorted and burning starter-cable. There was little damage and no injury to the driver. The fire was extinguished as a result of the driver manually operating the Ansul system.

Since the early telephone reports needed some clarification, a conference call was made to the mine foreman (Carrol Lopez) and truck operator (Chris Duhon). The recorded phone conversation allows a detail analysis of events surrounding the fire. In addition, FMC will visit the mine during the week of September 12 to photograph and obtain additional information of the truck fire.

A summary of the truck fire as recorded from the telephone conversation is as follows:

As the truck was leaving the underground crusher, the driver noticed smoke coming from the battery box area which is located under the floor plates on the passenger side.

The driver stopped the vehicle, shut down the engine and moved across the cab to the passenger side where he lifted the battery box cover. He saw more smoke, sparks and heard arcing sounds. He immediately pulled the battery cable, which was said to be very loose, off the terminal post. As he was looking through the smoke to see if fire existed, he heard another driver, some 100 yards away

yell out that fire and flames were under the truck. The driver then depressed the Ansul manual fire extinguishing actuator and jumped 4-5 feet to the ground.

The dry chemical powder discharged immediately and enveloped the entire vehicle. The powder cloud was said to have put out the fire quickly and there was no reflash.

The only vehicle repair necessary was new battery cable and the Ansul system recharged.

The vehicle was back on shift by 1:00 PM the following day after a new battery cable was installed and the Ansul fire extinguishing system recharged.

There is strong speculation that the fire began as a result of a grounded starter or starter cable and it actually began at the loading area some 1500 feet from the crusher where it was noticed. The truck was shut down during loading and the fire may have started when the ignition was turned on. The truck was not shut down at the crusher.

The driver said the green POWER light of FMC/USBM automatic fire protection system was on the entire shift and he did not notice any change in its condition just before, during or after the fire. Upon inspection, the FMC/USBM solenoid valve had released and punctured the pressurized cartridge. It was not known at what time this event occurred and it may be possible that actuation of the Ansul system caused sufficient live pressure to actuate the FMC/USBM valve.

Carrol Lopez commented that the fire was small and limited to the cable and residual oil in the immediate area. He estimated repair at about \$200.

CONCLUSIONS

1. Although it does not appear that the FMC/USBM system was thermally activated, a different response by the driver, such as jumping from the vehicle before actuating the manual system or if he was not in the immediate area, may have permitted the automatic system to activate. On the other hand, since the

3

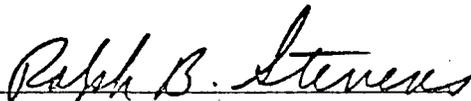
File

September 8, 1977

battery cable was burning, it may have also burned and shorted the FMC/USBM power cable that is connected to the cable connector on the battery post. A separate battery for the automatic FPS may be the ultimate answer.

2. The apparent valve operation caused by pressure from actuation of the Ansul system is not necessarily a detriment of the FMC/USBM system. The additional line pressure caused by two cartridges discharging (ie: Ansul manual system and FMC/USBM automatic system) will assure secondary actuation of the dry chemical cartridges. One-way check valves can be installed to prevent the FMC/USBM valve from actuating if desired.
3. The truck driver is to be commended on his excellent response to the fire situation. His response of shutting off the engine, searching for the fire source, and discharging the manual fire protection system were actions of an experienced and well trained employee of Diamond Crystal Mine.

The tape recording of this phone conversation was forwarded to Ken Bickel, USBM-TPO for his review.


Ralph B. Stevens

cmo

Appendix H

REPORT OF SYSTEM DISCHARGE

FMC Engineered Systems Division
Santa Clara

Interoffice

To Memo For Record Date 29 June 1977
From Ralph B. Stevens cc K. Bickel
A. Escover
Subject INADVERTANT DISCHARGE OF FIRE
EXTINGUISHING SYSTEM AT DIAMOND
CRYSTAL SALT MINE

Ron Blake and I called Carrol Lopez to learn the status of installation of new hardware sent by UPS last Thursday. He had not received the hardware but had news of a system discharge that occurred on the face cutter and wanted to give us as many facts as he could. There are still some questions that need answers before a final analysis can be made. The following comments were provided by Carrol:

- (1) Automatic discharge of the fire extinguishing system on the Goodman face cutter occurred during graveyard shift Friday 6/24/77.
- (2) There was no noticable fire, however, the vehicle power had tripped 4-5 minutes earlier.
- (3) The operator did not know why power tripped on vehicle but suspected it was overheating and running hot. He was thinking about calling an electrician when the system discharged.
- (4) All powder from the two Ansul tanks was discharged. Cartridges in the two Ansul actuators were still good and secured. The cartridge in the FMC/USBM solenoid valve was punctured as were the propellant cartridges on each of the powder containers.
- (5) The "tattle-tale" shear-wire securing the red DISCHARGE button on the FMC/USBM control panel was secure indicating the manual override system was not used.

29 June 1977

- (6) The operator said he did not touch anything; either before or after the discharge.
- (7) When Carrol arrived at the vehicle, the green POWER ON light was illuminated. He performed the 3-second test and all worked well.
- (8) The circuit breaker was not open (i.e.: in Out position). A brief discussion followed and past conditions of similar events on the crane were reviewed. There have been no problems with the system installed on the crane since larger batteries were installed.

Ron and I asked the following:

1. Was AC power off of the entire machine or just the operating motors? Our battery charging system is connected to the 110 VAC light circuit. Were lights on or off when system discharged?
2. Confirm that no one re-engaged the circuit breaker since we have never had a solenoid actuation without opening the breaker. The open breaker indicates a system actuation, removes power to solenoid and changes green light to yellow.
3. Did the red FIRE light illuminate and audible alarm sound prior to discharge. If machine was off, the beeping sound for 13 seconds should have been heard and the red light should be noticeable.

SUMMARY

The cutter vehicle was the one piece of equipment that I had serious doubts about the Ansul extinguishing system operating satisfactorily. A considerable thickness of salt and hydraulic oil accumulates over much of the vehicle and over the discharge nozzles.

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In this respect, it was good to hear that the extinguishing system functioned properly. Also, the fact that the vehicle power tripped 4-5 minutes prior to extinguishing system discharge (indicating a possible overheat condition) leads to speculation that the FMC/USBM system operated properly. An overheated motor may have allowed heat build-up sufficient for one of the six thermal switches to close and cause the discharge. All switches are 225° F set point except the cable reel switch which is 325° F. The control panel should have provided audible and visual alarm for 13 seconds prior to discharge and then change to yellow FAULT indication.

We will be able to make a better analysis of the situation after more facts are learned. One thing to consider is that if the vehicle temperature was such that the 225° F or 325° F thermal switches closed due to heat, there was probably flammable vapors present (i.e.: flash point of lubricating/hydraulic oils 200° F-500° F).

A spark or flame (cigarette) with the proper volume - ratio concentration of fuel and air would have caused a real fire.

Ralph B. Stevens
Ralph B. Stevens

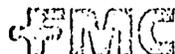
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Appendix I

AGENDA FOR THE FIELD DEMONSTRATION

FMC Corporation

Engineered Systems Division
328 Brookway Road, Box 450
Santa Clara, California 95052
(408) 269 0111



October 14, 1977

Mr. Ken Bickel
U. S. Department of Interior
Bureau of Mines
Twin Cities Mining Research Ctr.
P.O. Box 1660
Twin Cities Airport, MN 55111

Subject: In-Mine Demonstration, USBM Contract H0262052;
Automatic Fire Sensing and Suppression Systems
for Mobile Mining Equipment

Ref: FMC Letter Dated 7 October, 1977

Dear Ken:

The attached schedule and agenda for the in-mine demonstrations of automatic fire protection systems are forwarded for your review in accordance with contract requirements and referenced letter.

Verbal approval has been received from the mines for conducting the tests at Jim Bridger on Tuesday, November 8 and at Diamond Crystal on Thursday, November 10. I hope these dates and the agenda outline attached will comply with your schedule and approval.

Very truly yours,

A handwritten signature in cursive script that reads 'Ralph B. Stevens'.

Ralph B. Stevens
Associate Project Engineer

nd

Attachments

cc: A. Escover
R. Newhouse



MINE FIRE PROTECTION
 SYSTEMS DEMONSTRATION
 FMC/USM CONTRACT H0262052

AGENDA

PURPOSE: To review the performance of four automatic fire sensing and suppression systems on mobile mining equipment and to observe and record on film, automatic actuation and systems discharge during simulated fire conditions.

<u>TIME</u>	<u>EVENT</u>
9:00 AM	General Meeting: Review installation and monitoring events. Slides and handouts will identify the different systems installations, changes, and events during the ten month test effort.
10:00 AM	Board transportation to vehicles for discharge demonstrations
10:30 AM - 1:30 PM	Conduct simulated fire tests to activate alarm and automatic discharge of FMC/USM systems installed on coal hauler, ash hauler, dragline and front-end loader
2:00 PM	Return to conference room
2:30 PM - 3:00 PM	Short review meeting to conclude test program

LOCATION: The Jim Bridger Mine
 Rock Springs, Wyoming

DATE/TIME: November 8, 1977
 9:00 AM - 3:00 PM

ROUTE AND ACCOMMODATIONS: The Jim Bridger Mine is 45 minutes east of Rock Springs, Wyoming. Rock Springs connects to Denver, Salt Lake City, and other air routes via Frontier Airlines. Driving time from Salt Lake is 3.0 - 3.5 hours. The Outlaw Inn or Holiday Inn are suggested motels although others are available.



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ACERBA

MINE FIRE PROTECTION
SYSTEMS DEMONSTRATION
FMC/USBM CONTRACT H0262052

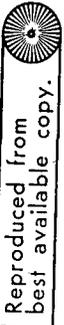
PURPOSE: To review the performance of four automatic fire sensing and suppression systems on mobile mining equipment and to observe and record on film, automatic actuation and systems discharge during simulated fire conditions.

LOCATION: Diamond Crystal Salt Mine
Jefferson Island, Louisiana

DATE/TIME: November 10, 1977
8:30 AM - 4:00 PM

ROUTE AND ACCOMMODATIONS: Jefferson Island is 15 minutes from New Iberia, Louisiana. Commercial air service to Lafayette (45 minutes driving time) or New Orleans (2.5 hours). Acadiana Motor Lodge in New Iberia (318) 465-6711.

<u>Time</u>	<u>Event</u>
8:30 AM	General Meeting: Review installation and monitoring events. Slides and handouts will identify the different systems installations, changes, and events during the ten month test effort.
9:30 AM	Prepare for underground demonstrations
10:00 AM	Enter mine and travel to vehicles for discharge demonstrations
10:30 AM- 2:30 PM	Conduct simulated fire tests and automatic discharge of FMC/USBM systems installed on cutter, crane, truck, and front-end loader
3:00 PM	Exit mine
3:30-4:00 PM	Short review meeting to conclude test program



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