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Design and Operation of Four Prototype Fire Detection Systems in Noncoal Underground Mines

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CONTENTS

	<u>Page</u>
Abstract.....	1
Introduction.....	2
Fire detection system for a timbered salt mine shaft.....	2
Smoke detection system for a multilevel copper mine.....	6
Spontaneous combustion fire warning system for a deep silver mine.....	10
Computerized fire detection system for an underground trona mine.....	12
Conclusions.....	17
References.....	18
Appendix.....	19

ILLUSTRATIONS

1. Layout of shaft fire detection system.....	3
2. Thermistor strip shaft fire detector and junction box attached to shaft timber.....	4
3. System control panel in headframe building.....	4
4. Shaft fire detection system annunciator panel in hoist house.....	4
5. Installation of thermistor strip shaft fire detector from a canopy above the man cage.....	4
6. Annunciator panel during system test showing alarms and digital hotspot indicator.....	5
7. Mineworthy ionization-type combustion particle (smoke) detector.....	6
8. Digital telemetry module mounted inside detector cap.....	7
9. Installation of ionization-type combustion particle (smoke) detector at the 500-250 ramps.....	7
10. Mine map on video display showing location and output of detectors in the collar-decline area, the oxide extraction area, and the sulfide extraction area.....	8
11. Video display showing three-key function commands.....	9
12. Layout of major elements of spontaneous combustion detection system.....	9
13. Spontaneous fire warning system detection instruments.....	10
14. Draw tube supplying mine air from fan cowling to detection instruments...	11
15. Strip chart recorder in guard shack.....	12
16. Telemetry interface modules adjacent to detection instruments.....	12
17. Telemetry interface modules in guard shack.....	13
18. Typical chart recording showing elevated CO levels following end-of-shift blasts.....	13
19. Layout of major elements of trona mine fire detection system.....	14
20. Added remote unit A attached to existing remote unit.....	14
21. Master station.....	15
22. Thermistor line-type detection at conveyor drive.....	16
23. Carbon monoxide and smoke detection instruments located downstream of the conveyor drive.....	16
24. Ultraviolet flame detector in grease niche area.....	17

TABLE

A-1. Temperature versus resistance for thermistor strip shaft fire detector...	19
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DESIGN AND OPERATION OF FOUR PROTOTYPE FIRE DETECTION SYSTEMS IN NONCOAL UNDERGROUND MINES

By William H. Pomroy¹ and Robert E. Helmbrecht²

ABSTRACT

Fires in underground metal and nonmetal mines pose a threat to the safety of underground miners and to the productive capacity of this Nation's mines. Contaminated air (smoke, carbon monoxide, and other products of combustion) is the primary life safety hazard created by a mine fire. The most reliable defense against the hazard posed by the rapid spread of contaminated air underground is early warning fire detection and rapid evacuation. This Bureau of Mines report describes the design and operation of four prototype early warning fire detection systems, for underground noncoal mines, presently undergoing prolonged in-mine testing by the Bureau. The systems are described within the context of the underground mine environment.

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Carbon monoxide, carbon dioxide, and submicron particulate detectors used separately or in combination, have been used successfully to provide early warning of shaft fires (4), however these detectors require occasional maintenance and calibration. Industrial-grade thermal fire detection devices are generally characterized by high reliability and durability but low maintenance requirements, even when used under the harshest conditions. Clearly, these attributes are desirable for mining applications.

One limiting feature of thermal detectors is that they rely on convected thermal energy for response. The distance between the detector and the fire, the relative spatial orientation and placement of the detector relative to the fire, and local air currents profoundly affect detector performance. Thus, in order to provide for large area coverage, numerous closely spaced detectors are required. A common example of thermal detection in the mining industry is the typical conveyor belt fire detection system mandated for underground coal mines (5). Spot-type, thermal detectors, spaced at 125-ft intervals along the entry provide early warning of a belt fire.

A string of spot-type detectors arrayed in a similar manner in a mine shaft is a feasible approach to shaft fire detection, however, the use of a line-type device would offer superior performance. A line-type device senses the heat from a fire at any point along its length. It can be thought of as spot-type detection in the limiting case where the distance between adjoining detectors equals zero.

Limited success has been achieved using fusible contact line-type thermal sensors in shafts (3). However, fusible contact line-type sensors are subject to occasional false alarms and considerable effort may be required to restore the detector to proper operation following an alarm, especially if the contact occurs in a section of the shaft for which access is difficult. An alternative to the fusible contact detector is thermistor strip.

A prototype thermistor strip fire detection system for mine shafts was developed by the Bureau and installed in the

1,200-ft main production shaft of a salt mine in Detroit, MI. The system was installed along the entire length of the shaft (fig. 1). The detector is described in detail in the appendix.

The system provides two alarm temperature settings, permitting a prealarm at a lower temperature and an alarm at a higher temperature. The system also includes a hotspot indicator that pinpoints the location of the overheated area and provides digital readouts of the distance between the shaft collar and the hotspot.

The system has three main subsystems: the sensor element in the shaft, the system control panel in the headframe-crusher building, and an alarm annunciator panel in the hoist house. The detector is positioned roughly in the center of the two-compartment shaft. It is attached at each timber set with special mounting brackets, thereby providing support for the detector at approximately 4-ft intervals. The detector is divided into two zones, the upper zone and the lower zone, with the two thermistor cables joined in a junction box at the shaft midpoint (fig. 2). The system control panel (fig. 3) contains all control circuits, backup power supply, and means for calibrating and troubleshooting the system. The annunciator panel (fig. 4), within sight of the hoist operator, provides a green lamp indicating normal system operation, visual and audible indication of prealarm and alarm conditions, and a digital display of the hotspot location.

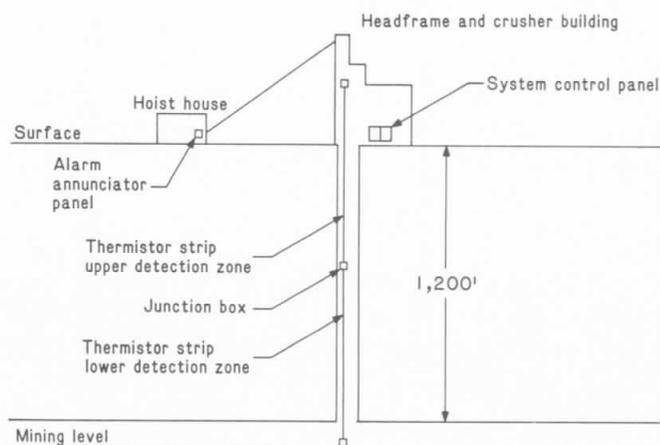


FIGURE 1. - Layout of shaft fire detection system.

The system was completely installed by a three-person crew over a 4-day period in April 1982. The detector was installed from a platform above the skip (fig. 5) by interconnecting ten 120-ft detector segments end to end. Because this shaft is the main mine exhaust, the air is laden with salt. This highly corrosive atmosphere is detrimental to the operation of electrical systems, necessitating great care in hermetically sealing each detector segment interconnection with a silicone adhesive-sealant. All external parts of the detector wire and connections are stainless steel which has been further protected with a corrosion-resistant Teflon⁴ fluorocarbon polymer jacket. The control panel and annunciator panel are housed in dust-tight enclosures. Following installation, the system was functionally tested. At a known elevation in the shaft, a propane torch was used to heat a section of the detection cable. The prealarm and alarm functions operated properly and the hotspot indicator displayed the correct elevation (fig. 6).

The system was operated continuously from April 1982 until June 1983 without hardware failure. Once during that period, a lightning strike at the headframe structure caused a momentary alarm, however, the system returned to the normal operating mode without further incident. These preliminary test results are significant because they indicate that the hardware and installation precautions are suitable for this worst case corrosive environment.

In June 1983, mine officials reported a system failure. A technician was dispatched to the mine to inspect the system, determine what repairs and/or equipment replacement were required, and recommend system modifications (if any) needed to avoid future similar problems.

The technician found that four 120-ft detector segments in the shaft had been ripped from their mountings by an object

⁴Reference to specific products does not imply endorsement by the Bureau of Mines.

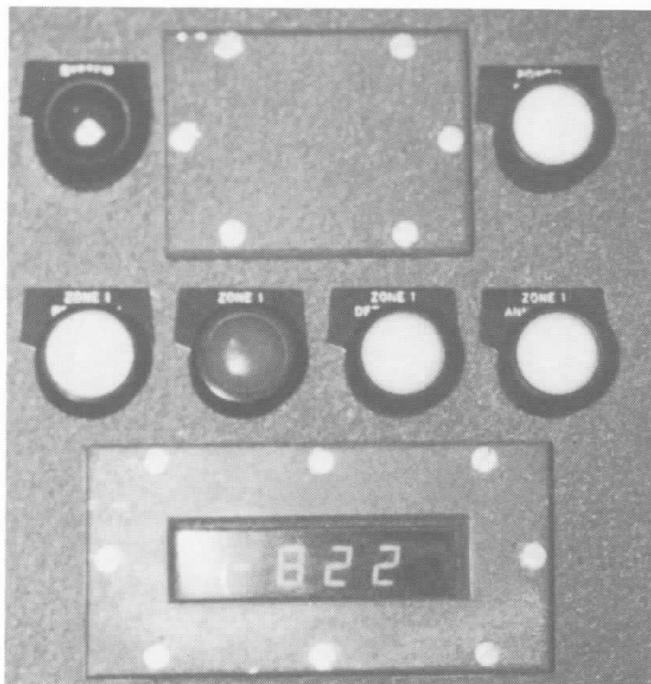


FIGURE 6. - Annunciator panel during system test showing alarms and digital hotspot indicator.

protruding from the skip. All four segments needed to be replaced. As a precaution to prevent further damage in the future, it was recommended that a 1/8-in-diam stainless steel messenger cable be installed in the shaft parallel to the detector and flush with the timber sets. The detector could then be removed from the mounting brackets and attached to the messenger. This mounting arrangement would (1) draw the detector closer to the timber sets so that it will be less likely to become entangled with objects protruding from the skip, (2) permit the detector to be secured at intervals closer than the 4-ft spacing of the timber sets, and (3) provide greater overall strength to the installation because the stainless steel messenger cable is much stronger than the detector.

Repairs to the damaged portion of the detector have been delayed because of a production shutdown at the mine. Replacement of the damaged segments and installation of the messenger will be effected and testing continued upon re-opening of the mine.

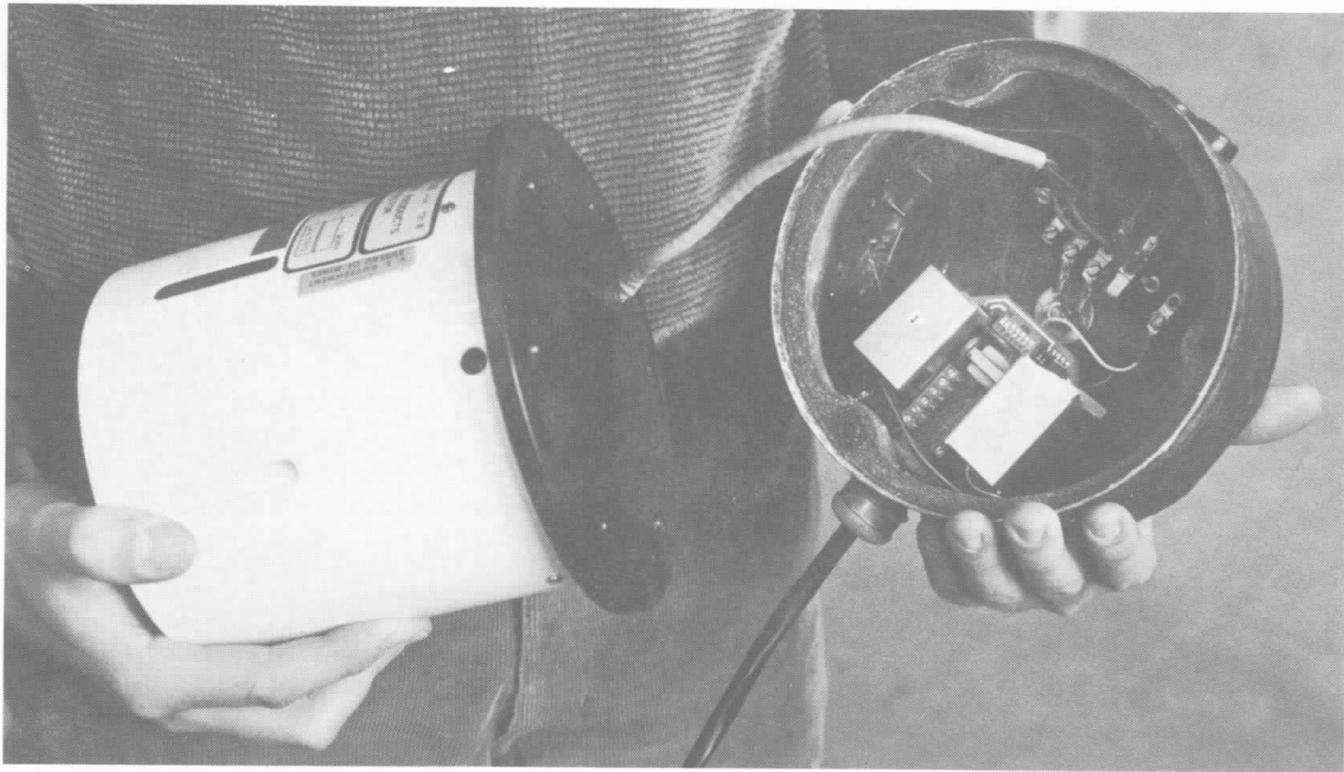


FIGURE 8. - Digital telemetry module mounted inside detector cap.

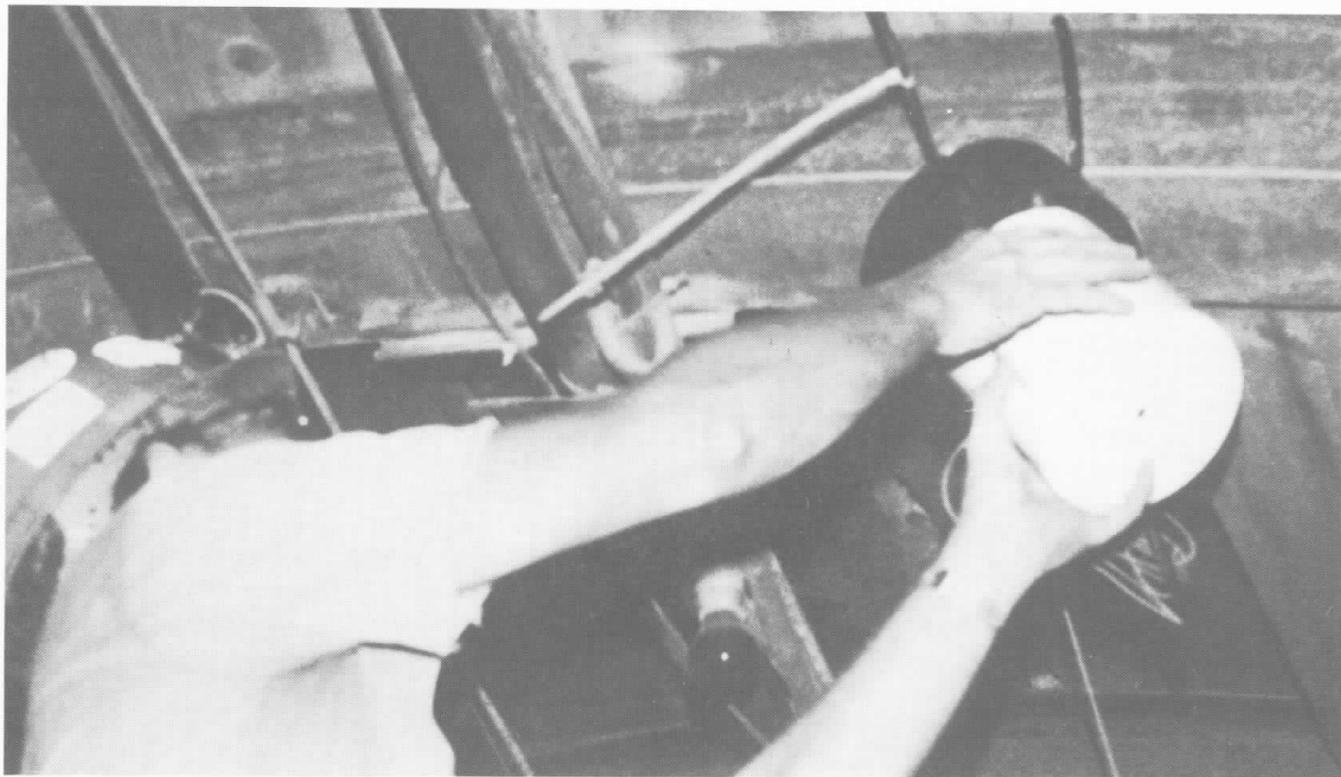


FIGURE 9. - Installation of ionization-type combustion particle (smoke) detector at the 500-250 ramps.

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THIS IS A MINE FIRE SENSING SYSTEM
DISPLAY AND CONTROL TEN SMOKE DETECTORS
ARE SPREAD THROUGHOUT THE MINE VIA
A DEDICATED TELEPHONE LINE. AUTOMATIC
ALARMS WILL INDICATE EXCESSIVE PARTICU-
LATE LEVELS BY A STEADY TONE AND SCREEN
DISPLAY SHOWING THE MINE AREA AFFECTED.
6/ 5/84 10:46: 6
MENU
IF PRINTER COPY IS NEEDED TYPE IN [P]
AS FOURTH CHARACTER FOLLOWING THREE
CHARACTER COMMAND. PRINTABLE REPORTS
ARE DESIGNATED BY #.

P S A = PRESENT SENSOR ALARMPPOINT #
C S A = CHANGE SENSOR ALARMPPOINT #
P S T = SENSOR'S PAST TABLE #
P S G = SENSOR'S PAST GRAPH #
C O L L A R / = COLLAR / DECLINES MAP
O X I D E = OXIDE EXTRACTION MAP
S U L F I D E = SULFIDE EXTRACTION MAP

ENTER COMMAND, HIT RETURN: █

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FIGURE 11. - Video display showing three-key function commands.

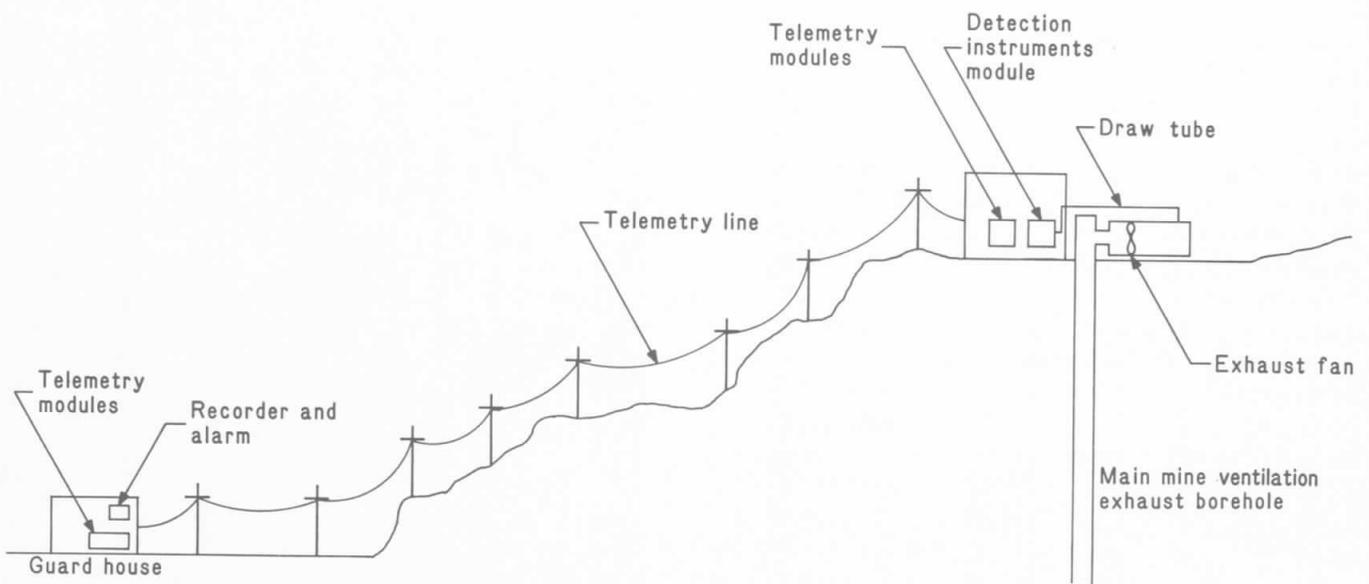


FIGURE 12. - Layout of major elements of spontaneous combustion detection system.

instruments, housed in a corrosion-resistant fiberglass enclosure (fig. 13), were supplied mine air through a draw tube linking the enclosure with the ventilation fan cowling (fig. 14). The system was linked by hard wire to strip charts in a guard house approximately 2,000 ft from the borehole (fig. 15).

Signal transmission is provided by a mineworthy telemetry system. Telemetry interface modules are located at each end of the telemetry line; i.e., in the emergency escape hoist house (fig. 16) and the guard house (fig. 17). The system accepts 1- to 0-V inputs for current loops from the detectors. Each wire pair can accommodate from 1 to 48 channels. Operating on a balanced line principle, and incorporating special line filters and protection networks, the system is noise immune and interference free.

The oxygen analyzer used in the earlier test program experienced excessive drift.

Consequently, it was replaced by a similar unit from a different vendor. However, this detector also suffered excessive drift and was removed approximately 1 week after installation. A second electrochemical cell carbon monoxide detector was later installed and connected to the former oxygen analyzer's telemetry channel. This redundancy provided an opportunity to observe tracking between the two carbon monoxide detectors.

After 12 months of system operation, the remaining detectors and telemetry system were functioning properly. Chart recordings indicated up to 15-ppm excursions in carbon monoxide values following end-of-shift production blasts (fig. 18). The two CO detectors track very closely, both at low levels and following the production blasts (the traces are slightly offset to facilitate data analysis). These readings have been validated by analyses of air samples collected at the time of the CO readings.

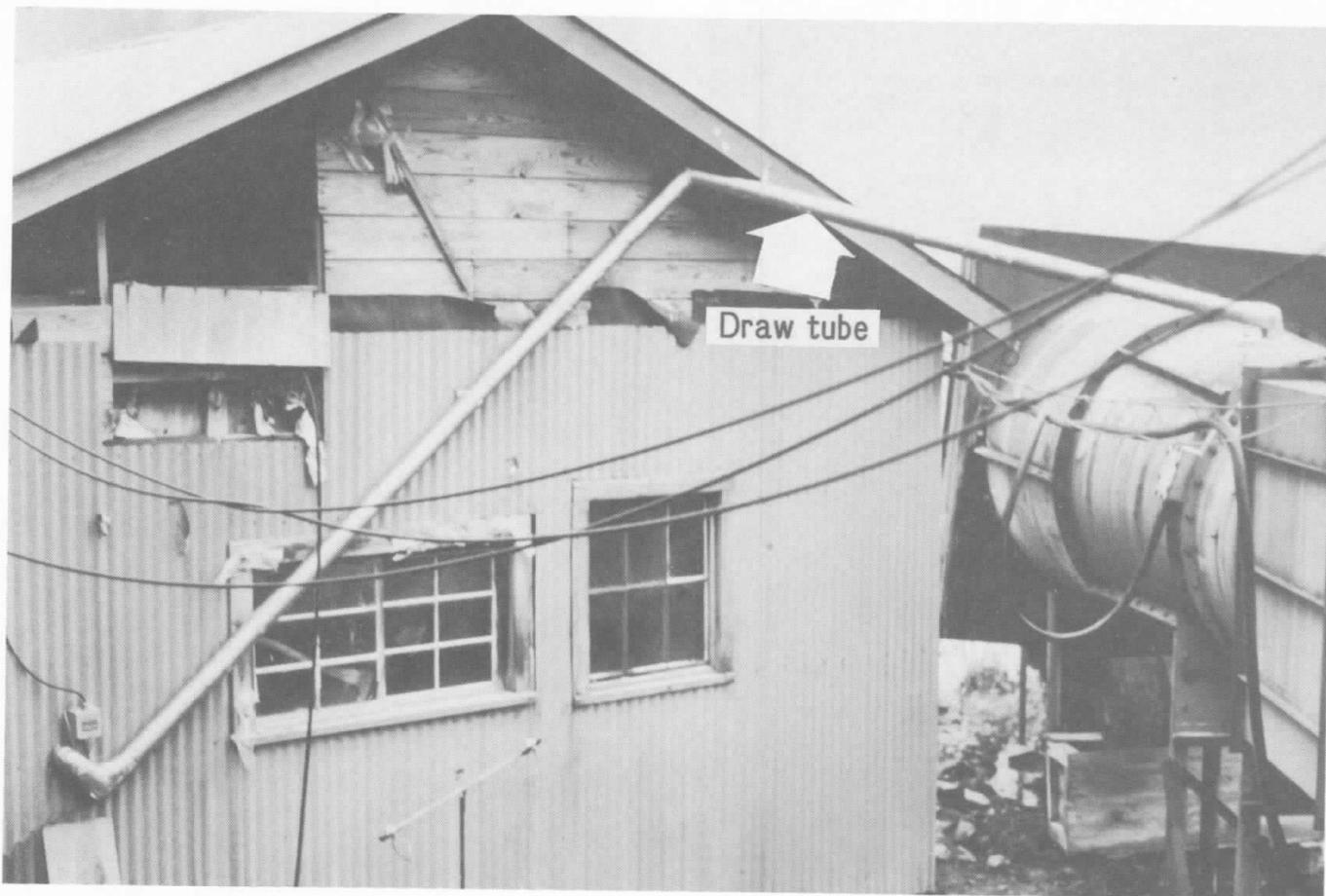


FIGURE 14. - Draw tube supplying mine air from fan cowling to detection instruments.



FIGURE 17. - Telemetry interface modules in guard shack.

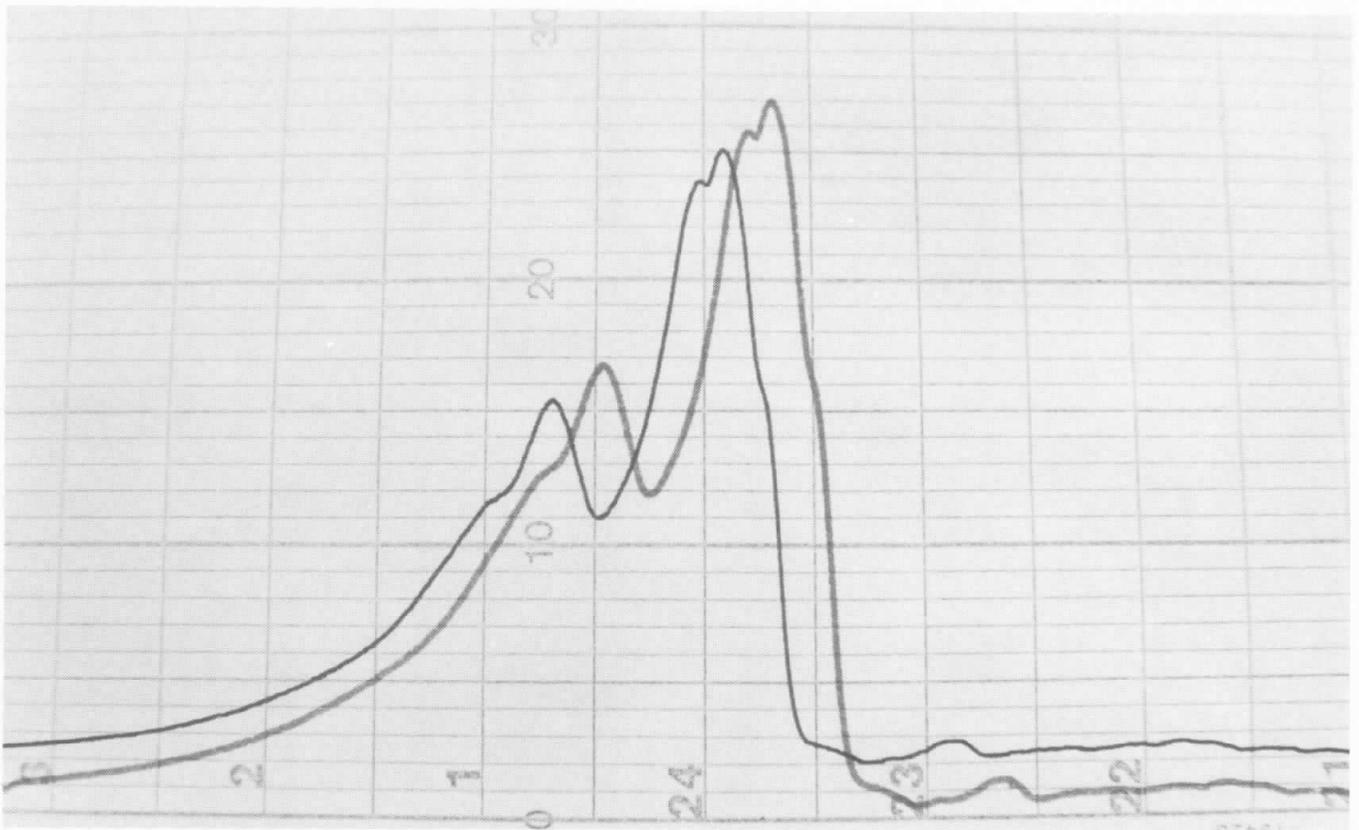


FIGURE 18. - Typical chart recording showing elevated CO levels following end-of-shift blasts.



FIGURE 21. - Master station.

form. The analog-to-digital conversion of the analog signals is accomplished by an incremental charge balancing technique.

The telemetry system within the remote units transmits all signals received from the fire detectors to the master station via FSK tone (frequency shift key tone modulation) transmission when called by the microprocessor located in the master station.

The transmitted data are temporarily stored and analyzed by the control microprocessor located in the master station. The submaster station serves as an alarm

setpoint control for the microprocessor, a present time status display of processed data, and an alarm annunciator. The alarm set point controls are digital thumb wheels that are used to set the desired alarm level for each measured variable. When the telemetered signal exceeds the set thumb wheel alarm level, the microprocessor initiates an alarm at the submaster station, which corresponds to the remote unit area and type of detector experiencing an alarm. Deactivation of the alarm is automatic when the telemetered variable drops below the setpoint level. The microprocessor also

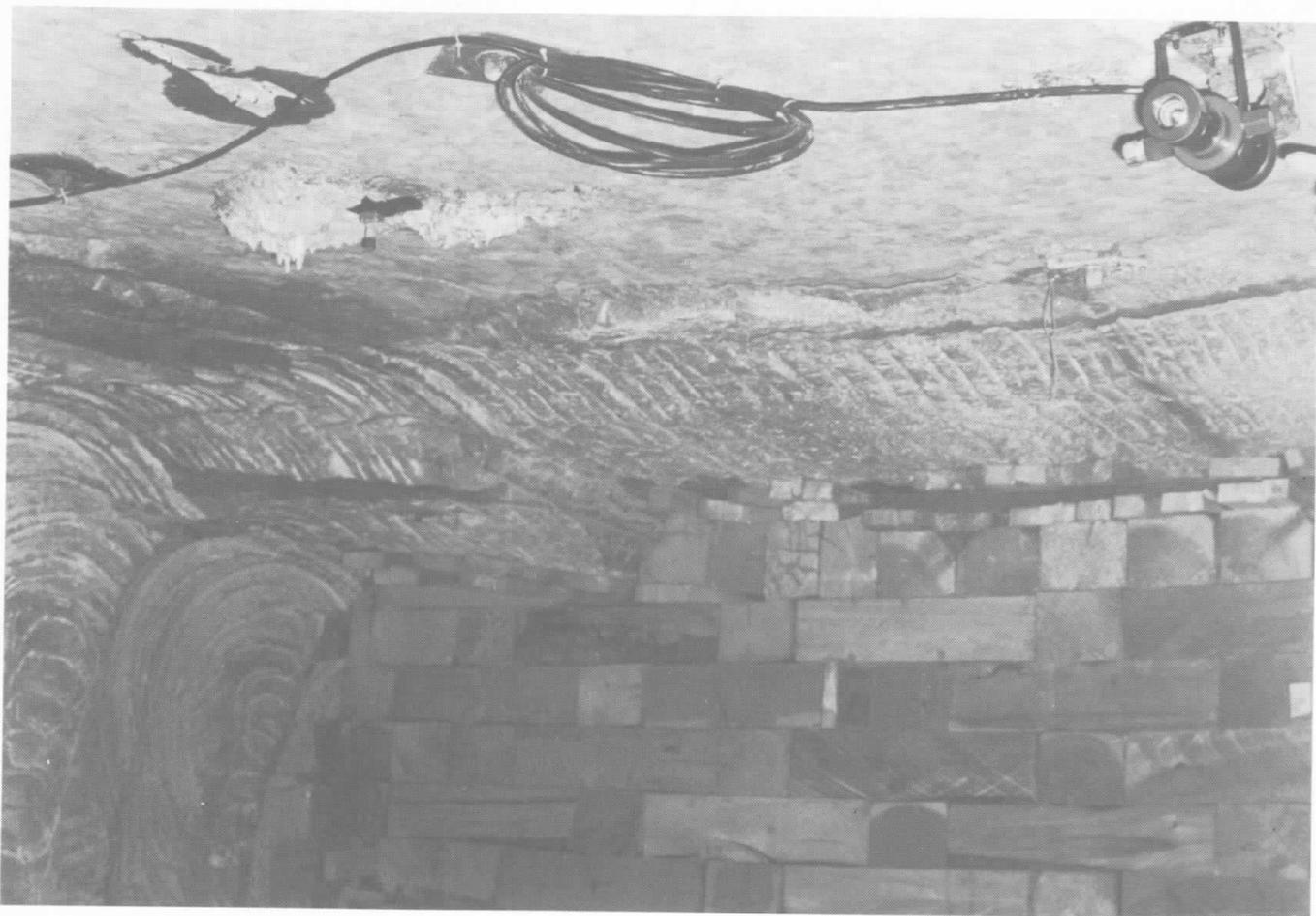


FIGURE 24. - Ultraviolet flame detector in grease niche area.

CONCLUSIONS

The elapsed time between the onset of a fire and its detection is critical because fires tend to grow in size and intensity with time. Early fire detection and warning permit the initiation of a mine's emergency plan (evacuation, fire fighting, etc.) while the fire is still small, or ideally, while it is still in the incipient stage. Fire detection and

warning systems, utilizing sensitive heat, flame, smoke, and gas analyzers, provide the most rapid and reliable indication of a developing fire. Testing of prototype equipment in a variety of mine settings has highlighted both deficiencies and advantages of various detection instruments and telemetry systems.

APPENDIX

THERMISTOR STRIP SHAFT
FIRE DETECTOR

The thermistor strip detection system selected for the salt mine shaft was the Alison Control A888-M106 Fire Detection System.

The control unit is housed in a National Electrical Manufacturers Association (NEMA) 12 enclosure. A separate annunciator is provided in a NEMA 9 enclosure. The system provides two independent, adjustable levels of alarm (prealarm and alarm) that are annunciated at both the control unit and annunciator. The location of the hotspot is also indicated in feet above or below ground level at the annunciator.

The sensor is completely supervised. An abnormal condition is indicated at the control unit and annunciator if an open or short occurs anywhere along the entire length of the sensor. All interconnections between the control unit and annunciator are also supervised.

The A888-M106 system requires 115 ± 10 V ac input power. The maximum power dissipation is 300 W.

The detection cable operates on 24 V dc generated by an internal ferroresonant power supply. Should the system lose ac input power, the power supply is automatically disconnected and standby batteries (located at the bottom of the control unit) are automatically switched in. The batteries are sufficient to power the system for 24 h in standby followed by 1 h in alarm. The system contains a battery charger that automatically maintains the batteries fully charged when ac power is present.

The annunciator is powered from the control unit at 24 V dc and is serviced by the control units backup batteries.

The sensor is composed of thirty 40-ft sections of Alison 9090-100 continuous thermistor cable. This cable consists of stainless steel tubing containing a specially formulated ceramic thermistor core. A center wire is imbedded in the core and runs the entire length of the sensor.

The sensor center-wire-to-case resistance exhibits a negative temperature coefficient. This means that as the temperature increases, the resistance of the sensor decreases exponentially. It is this decrease in resistance that is sensed by the alarm instrumentation. Table A-1 displays the temperature-resistance relationship for 9090-100 series cable. It should be noted that the sensor will detect a high temperature on a short length of the cable as well as a lesser temperature over a longer length of the cable.

TABLE A-1. - Temperature versus resistance for thermistor strip shaft fire detector

Temperature, °F	Resistance, Ω
50.....	1,000,599,928
100.....	69,098,544
150.....	7,397,155
200.....	1,111,113
250.....	218,002
300.....	52,998
350.....	15,343
400.....	5,131
450.....	1,935
500.....	808
550.....	368
600.....	180
650.....	94
700.....	52
750.....	30

The 40-ft sensor sections are connected in series to form two sensor circuits each 600 ft (15 sections) in length. Each 600-ft circuit is monitored separately. The two circuits meet at an elevation of 580 ft where they are terminated in a stainless steel junction box. Stainless steel junction boxes are also provided at the -1,180- and +20-ft elevations to terminate the other ends of each sensor circuit. The entire sensor length and all three junction boxes are coated with a heavy polymer jacket for further protection from the corrosive atmosphere.

Internally the Becon MK IV particle detector is comprised of a shielded single ionization chamber, a radioactive source, an ion collecting electrode (grid), and a current amplifier. Because of the inherent corrosive nature of the underground mine atmosphere, all internal components of the detector are made of plastic or are hermetically sealed.

The radiation source, which ionizes the air within the ionization chamber, is a sealed glass vial containing 5 mCi of krypton 85 gas. The vial is connected to the grid inside the ionization chamber by two cable ties.

The ionization chamber (conducting plastic chamber case) is constructed from conducting plastic and completely encircles the grid, also made of conducting plastic. The plastic chamber case is cylindrical in shape, but the circumference of its walls is not continuous. Instead, the wall is constructed from a number of overlapping curved rectangular plates of conducting plastic. These plastic plates are affixed to the disk-shaped base of the chamber case at two alternating radii about the mean circumference of the chamber. The longer edges of the rectangular plates run parallel to the axis of the chamber case. This staggering of the sides of the chamber case wall allows mine air to enter the chamber and causes further baffling of the mine air velocity. The plastic chamber case of the ionization chamber acts as the ground electrode with respect to the grid, which is the negative electrode. Because the plastic chamber case along with the conducting plastic upper case are at ground potential they electrically shield the ionization chamber and all internal electronics from electromagnetic radiation external to the detector.

The hermetically sealed amplifier electronics and the grid are electrically isolated from the conducting plastic cases, by a deep annular grooved insulator and conductive plastic guard ring. The annular grooves are present to create the longest possible leakage path between the grid and the case. Electrical leakage could occur if high humidity saturates the inside of the detector with moisture or if a conductive dust is

present in the mine atmosphere and eventually settles within the detector. The annular grooved insulator also serves the purpose of supporting the grid and amplifier electronics. The guard ring prevents leakage, by its connection to the non-inverting terminal of the operational amplifier. The inverting terminal of the operational amplifier, which is connected to the grid, is maintained at the same potential as the non-inverting terminal, therefore no potential difference can exist between the guard ring and the grid, which results in no current flow.

The Becon MK IV detector is a single ionization chamber analog output particle detector. The conducting plastic chamber case and the grid are separated by a potential difference of approximately 10 V. This potential difference, with ionized air as the medium, produces an ionization chamber base current of approximately 0.5 nA. The 5-mCi krypton 85 beta radiation source (half-life of 10.8 yr) is used to ionize inflow air. The ionization current across the ionization chamber is adjusted by varying the potential across the case and the grid to yield an ionization current level proportional to a -0.9-mA output current. This base ionization current level corresponds to the particle concentration in normal ambient mine air.

The potential difference between the case and the grid remains essentially constant, however, the ionization current will vary depending upon the size and concentration of particles carried by the inflow air into the ionization chamber.

A charged smoke particle is much heavier than an air molecule, therefore its drift velocity due to the potential between the ionization chamber wall (case) and the grid is very small compared to the convective airflow velocity. The smoke particle also has a much larger surface area than an air molecule, which reduces the mean free path between collisions of the ions responsible for current flow, allowing for greater numbers of positive ion and electron recombinations. Because of recombination, the electron and ion mobility are reduced, which results in a detectable decrease in the ionization current.

voltage via a calibration curve (provided with each unit), unusual excursions from normal levels are readily apparent on strip charts and can trigger alarms.

In operation, the Spanair analyzer CO₂ signal shows a constant level of about 330 ppm, which is the concentration of CO₂ in normal atmospheric air. As incipient heating occurs in combustible material, large volumes of CO₂ will be given off well before pyrolysis begins. The system will report these changes as a gradual increase in CO₂.

A receiver (surface unit) processes the analyzer output into alarm levels. The chart records input, voltmeter, and system failure signals. For long distance data transmission, a frequency-division multiplex telemetry system is utilized. Several remote analyzer heads can communicate over one balanced transmission line (two wires and suitable ground).

The only difficulties anticipated were a lack of published performance specifications and a lack of repair parts or maintenance service available from the Republic of South Africa. However, a competent technician can maintain the electronic circuitry and analyzer head with use of the furnished manual. The only anticipated maintenance consists of periodic cleaning of the particulate filter if the environment is dusty. Mirrors should be cleaned every few years to maintain a strong signal. Calibration requires an output adjustment to 1.0 V during nitrogen purge.

Mine fire detection systems are expected to operate under conditions that would normally disable laboratory instruments. Thus, performance data obtained under stable laboratory conditions do not fully predict performance expected for a mine where conditions are harsh and unstable. Laboratory tests were conducted to determine the degree to which the instrument is immune to such harsh and unstable conditions. Conditions that are expected underground and that are reproducible to a certain degree in the laboratory include the following:

1. Line voltage variation between 90 and 140 V ac.
2. Blackouts for long time periods.

3. Changes in temperature between 10° and 40° C.

4. Changes in ambient moisture level between 20 and 95 pct relative humidity.

The analyzer displayed a slight increase in sensitivity to CO₂ concentrations at temperature extremes, however, the problem is considered to be minor. The analyzer is not sensitive to changes in relative humidity or line voltages. Following power interruption, the instrument restabilizes within 1 minute after power is restored.

OVERHEAT DETECTION FOR CONVEYOR DRIVE

Overheat detection for the conveyor drives at the trona mine was provided with Edison Electronics model 377 control and model B fire detection (thermistor) cable. The 377 control is 2-1/2 by 1-3/4 in. in size; is wired through an eight-pin connector to power (24 V dc); contains a detection cable, audio alarm, and lights; and is mounted to electrical terminals inside a 6- by 8-in corrosion resistant box. The model B fire detection cable is a thermistor; that is, a temperature sensitive resistor. The model B cable is tubular, 0.070 in. in total diameter, with a 0.020-in-diam iron wire center conductor imbedded in a 0.010-in-thick layer of metal oxide semiconducting material. It is 20 ft long and operates within the temperature range of -40° to 2,000° F.

The model B fire detection cable is similar to the cable used in the salt mine shaft. It is constructed with a metallic outer sheath and a metal wire as the center conductor. They are electrically isolated from each other by a cylindrical semiconductor layer. The thermistor's resistance between conductors is depicted by a negative temperature coefficient with a drop in resistance that is nearly exponential with a linear increase in temperature. The rate at which the resistance drops and the temperature at which it drops can be altered by varying the type and quality of the semiconductor material.

The semiconductor material used in the Edison model B fire detection cable has a

When the tube conducts it draws down the voltage across a capacitor. The extinguish voltage on the detector is in the region of 160 V, a level at which the ionization processes that support the discharge can no longer be maintained. At this point, the tube will stop conducting and the capacitor will recharge through a resistor that is a current limiting resistor. As the capacitor recharges, it will reach a voltage level in the vicinity of 250 V, which is the normal striking or starting voltage of the tube. If UV radiation of sufficient intensity is present at this moment, the tube will fire again, and this process will be repeated over and over as long as radiation is present. The more intense the radiation the more frequent the discharge rate of the detector.

The fire warning relay is closed when 25 or more discharges occur per second.

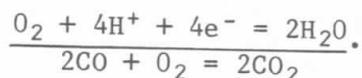
The DetTronics U7602 detector is also equipped with an UV test lamp that monitors the integrity of the optical lens and deenergizes a relay when the surfaces become obstructed with oil, dirt, or dust. The UV test lamp emits UV radiation that passes through the lens, reflects off a beveled reflecting ring mirror, passes back through the lens and into the tube.

CARBON MONOXIDE DETECTION

Carbon monoxide detection for the spontaneous combustion fire warning system and the trona mine fire detection system was provided by the Energetic Sciences Ecolyzer 4000 and the MSA 571.

Both the MSA 571 and the Ecolyzer 4000 are CO detectors that utilize the electrochemical properties of a fuel cell to sense CO. Input power to both of these detectors is 120 V ac. The electrochemical sensor is constructed of three

electrodes--the sensing electrode, the reference electrode, and the counter electrode--all suspended in an acid solution. The materials to be chemically reacted are CO and oxygen gases from the mine's ambient air. These gases diffuse into the acid (or in the case of the Ecolyzer 4000 are pumped into the fuel cell by an air pump) solution and ionize. Refer to the following half reactions:



The CO is electrochemically oxidized at the sensing electrode while oxygen reduction occurs at the counter electrode. The ion concentration in the acid solution because of the dissolved gases is proportional to the concentration of CO in the air; likewise, the current flow through the cell is proportional to the ion concentration in the solution. Therefore, the current flow through the cell is proportional to the CO content of the air. This current flow is then amplified and compensated for temperature before it is sent to the sensor control.

The MSA 571 and Ecolyzer 4000 CO detectors are very similar in their function. Their input amplifiers generate a 1-V full-scale analog signal output from the signal received from the sensor cells. The input amplifier drives a meter on the detector's front panel and also provides a 0- to 1-V output proportional to the CO concentration. Operational amplifiers used as voltage comparators monitor the output voltage of the input amplifier. When this output voltage reaches a level proportional to 20 ppm, the warning relay activates; at a level proportional to 50 ppm, the alarm relay activates.

