BuMines OFR 111(1)-77

EXECUTIVE SUMMARY
OF
FINAL REPORT, VOLUME I

BUREAU OF MINES
CONTRACT HO252038

AUTOMATIC FIRE PROTECTION SYSTEM FOR MOBILE UNDERGROUND METAL MINING EQUIPMENT

Bureau of Mines Open File Report 111(1)-77

THE ANSUL COMPANY

INTRODUCTION

The object of the Bureau of Mines research contract HO252038 was to select the type of mobile, underground metal and nonmetal mining equipment which presented the greatest overall fire hazard; develop a reasonably priced, reliable, automatic fire protection system for that vehicle; and demonstrate performance by on-vehicle fire tests in an underground mine. The contract started June 21, 1975 and extended through June 30, 1976.

As mine operators attempt to become more productive they tend to require more and more mechanized mobile equipment, and the equipment becomes larger, more complex, and more expensive. Because of the increased density of underground diesel powered vehicles and the hydraulics, fuels, and electric equipment associated with these vehicles, the potential fire hazard is increasing.

SYSTEM DEVELOPMENT AND TESTING

Data for the hazards analysis and generation of the design concept were acquired through visits to twenty mine sites in ten states and Canada, visits to Bureau and MESA facilities, and a literature survey. Load haul-dumps were identified as the class of mobile underground equipment found to constitute the greatest overall fire hazard. The hardware design requirements of a fire protection system were established for this type of vehicle.

A recommended concept and four alternatives were prepared and presented to the Bureau. The recommended system as described by the following block diagram was approved by the Bureau for the development phase. Although most of the reported fires were controlled or controllable with portable extinguishers or manual systems, the automatic fire protection system concept is proposed:

A. to give the operator warning of the presence of a fire

B. to provide for actuation of the system when the operator is incapacitated or has left the vehicle. (It is of interest that in one reported fire the operator left the vehicle to fight the fire with a portable. When the fire got out-of-hand the operator left the area, and the manual fire protection system which was on the vehicle was never actuated).

C. to shut down the engine automatically so that any pressure leaks of combustible liquids are stopped.

BIBLIOGRAPHIC DATA SHEET

1. Report No. BuMines OFR 111(1)-77
2.
3. Recipient's Accession No.

4. Title and Subtitle
Automatic Fire Protection System for Mobile Underground Metal Mining Equipment. Executive Summary of Final Report, Volume I

5. Report Date
June 30, 1976

6. Performing Organization Code

7. Author(s)
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8. Performing Organization Rept. No.

9. Performing Organization Name and Address
The Ansul Company
Marinette, WI 54143

10. Project/Task/Work Unit No.

11. Contract/~~Grant~~ No.
H0252038

12. Sponsoring Agency Name and Address
Office of Assistant Director--Mining
Bureau of Mines
U.S. Department of the Interior
Washington, DC 20241

13. Type of Report & Period Covered
Contract research

14. Sponsoring Agency Code

15. Supplementary Notes
Approved for release by Director, Bureau of Mines, June 27, 1977.

16. Abstracts
The objective of this report was the development and in-mine testing of an automatic fire control system (AFCS) for mobile underground metal mining equipment. The report covers the period from June 21, 1975 through June 30, 1976, and accomplished the following tasks: (1) Preparation of data handling plan and data acquisition which included visits to 20 mine sites in 11 States, visits to Bureau of Mines and Mining Enforcement and Safety Administration facilities, and a literature survey. (2) Data analysis that determined the most hazardous type of vehicle for use in the demonstration, and design requirements for the AFCS. (3) Development of recommended design concepts for the AFCS. (4) Design and development of the AFCS including tests on a full-scale mockup of a load-haul-dump (LHD) vehicle. (5) Underground fire tests on an ST-2B-LHD vehicle at the Hecla Lakeshore mine in Casa Grande, Ariz.

17. Key Words and Document Analysis. 17a. Descriptors

Metal and nonmetal mining
Mobile underground mining equipment
Fire extinguishing system
Fire detectors
Fire hazards

17b. Identifiers/Open-Ended Terms

17c. COSATI Field/Group 08I, 17C

18. Distribution Statement
Release unlimited by NTIS.

19. Security Class (This Report) UNCLASSIFIED

20. Security Class (This Page) UNCLASSIFIED

21.

22. Price PCA11 MFA01

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11. **Contract/Grant Number.** Insert contract or grant number under which report was prepared.

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13. **Type of Report and Period Covered.** Indicate interim, final, etc., and, if applicable, dates covered.

14. **Sponsoring Agency Code.** Leave blank.

15. **Supplementary Notes.** Enter information not included elsewhere but useful, such as: Prepared in cooperation with . . . Translation of . . . Presented at conference of . . . To be published in . . . Supersedes . . . Supplements . . .

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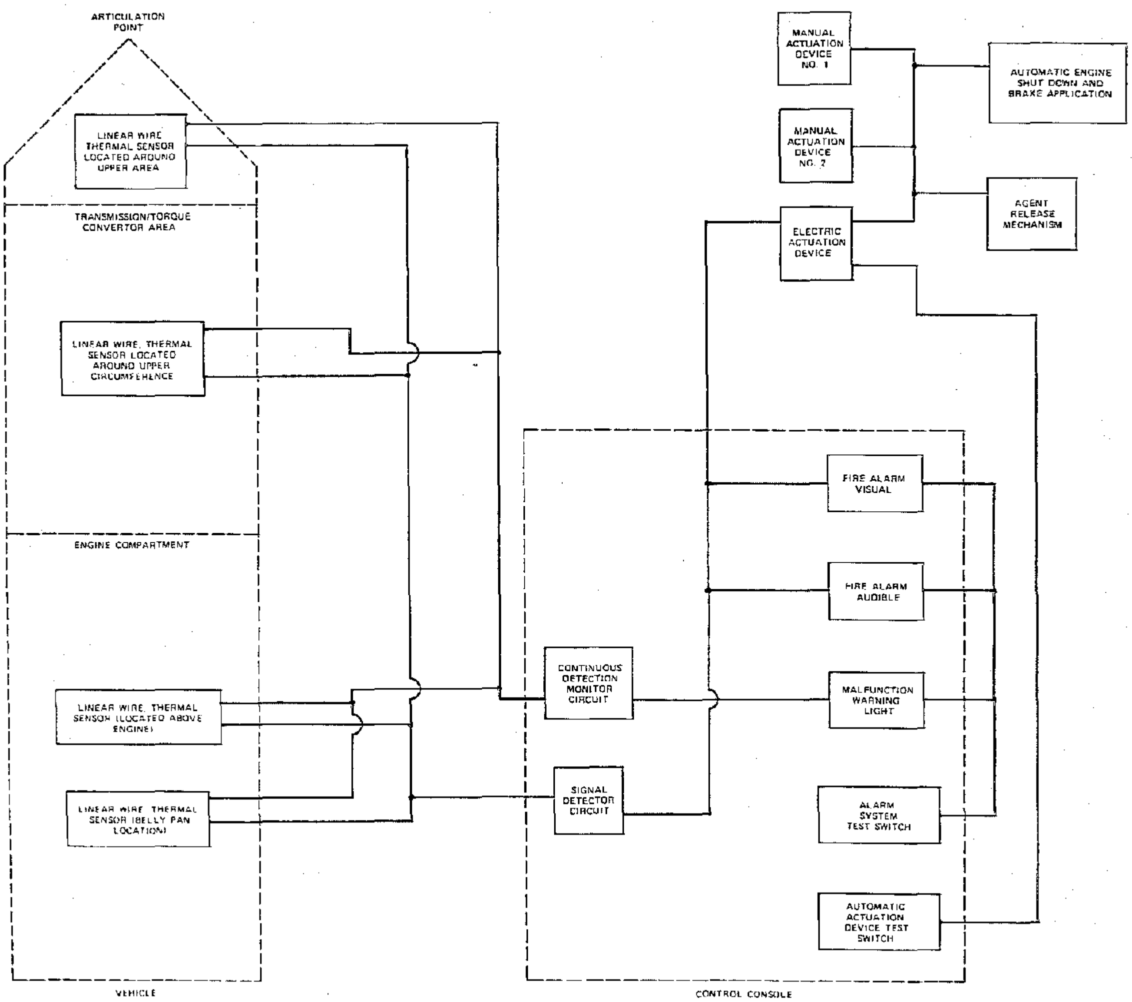
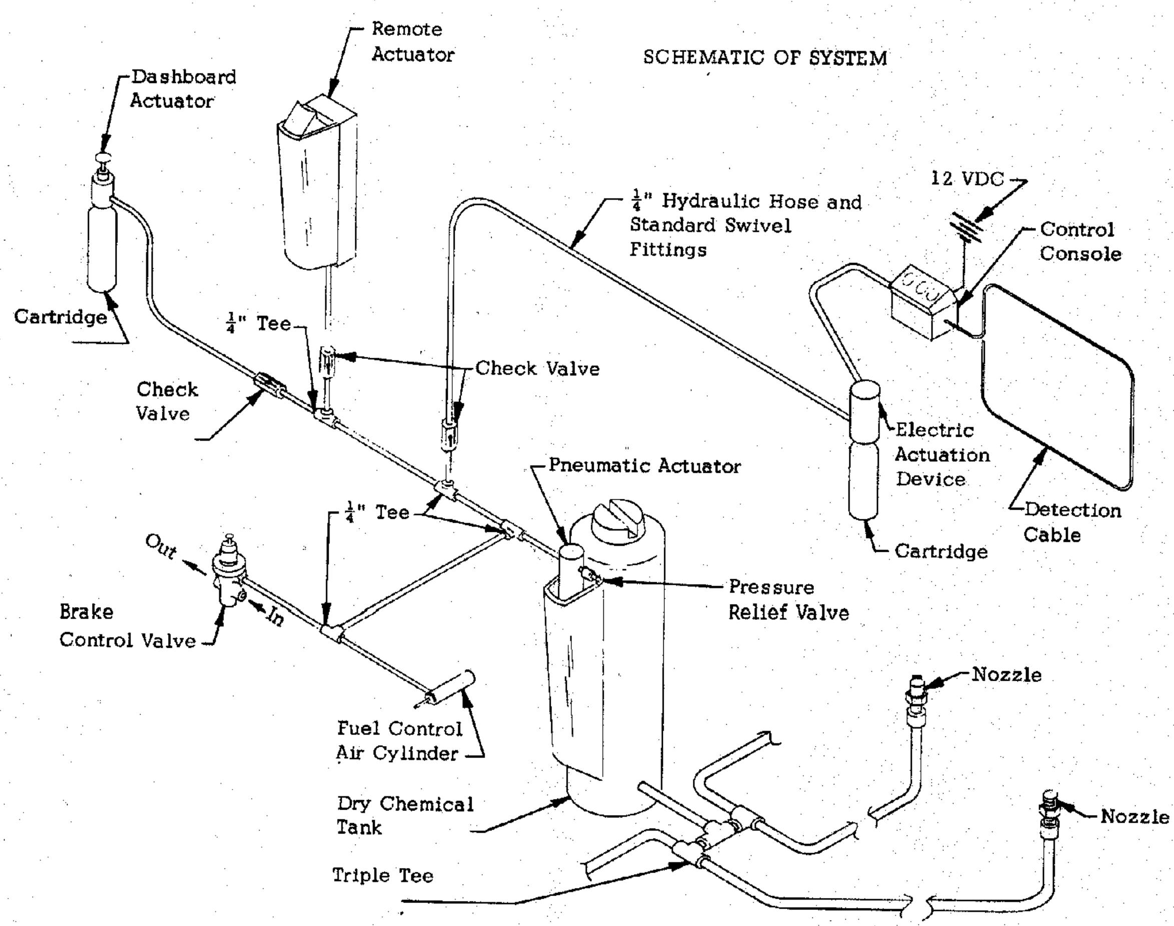
AUTOMATIC FIRE CONTROL SYSTEM SCHEMATIC

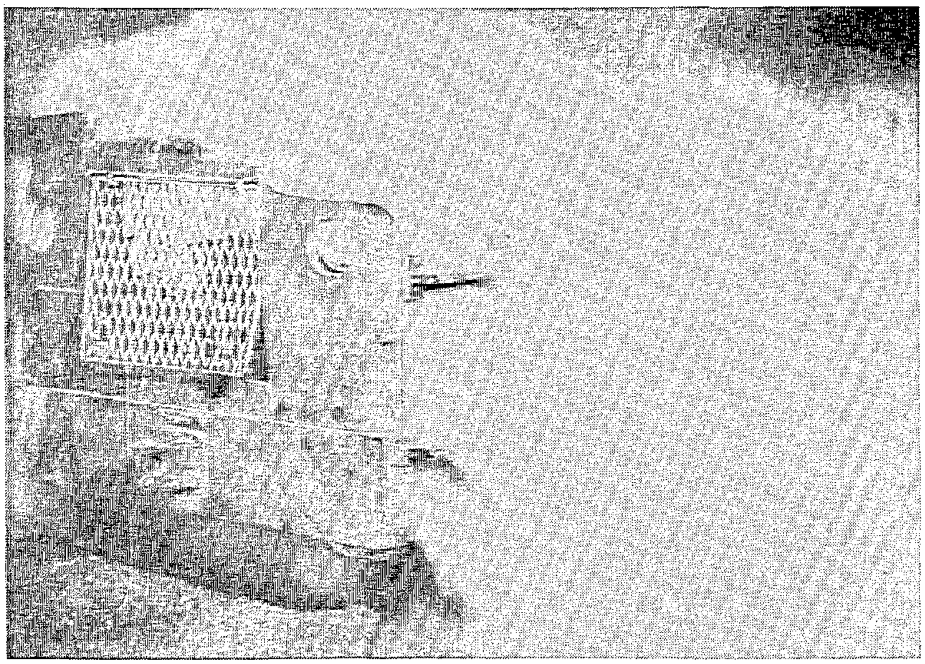


D. to set the vehicle brakes automatically when the system is actuated. The automatic braking action is delayed and gradual as the pneumatic pilot pressure decays.

The approved design concept was expanded to the specific design of a system for the ST-2B-LHD vehicle including the selection of specific components for this system. A prototype system and test components were procured and factory tests on a full scale, vehicle mock-up were performed as required to demonstrate the capability of the prototype AFCS for the underground mine test. The development tests also included component tests where it was determined that previous component history should be supplemented to satisfy the special mine environment. The system is illustrated by the schematic below.



The system was then installed on an ST-2B-LHD in the Hecla Mining Company's Lakeshore Project, Casa Grande, Arizona. System discharge tests were performed in the mine with head-winds of 3.4 and 19.3 mph to demonstrate that the dry chemical discharge patterns were effective. On May 13, three actual fire tests were performed.



DISCHARGE OF SYSTEM IN MINE

During the discharge of the dry chemical agent in the confines of the exhaust drift the obfuscation problem was limited to the driver on the vehicle. Miners in the area of the vehicle would not be hindered in their movements by the dry chemical release.

CONCLUSIONS

The objectives of the contract were all successfully accomplished. The load-haul-dump class of vehicles was selected as the greatest potential fire hazard, and an automatic fire protection system was developed for a vehicle in that class. The prototype hardware successfully demonstrated its capability to detect and extinguish fires in an underground mine environment.

RECOMMENDATION

Long term testing of prototype systems on vehicles in the mine environment is needed to demonstrate system reliability and cost effectiveness.

Foreword

This report was prepared by The Ansul Company of Marinette, Wisconsin under USBM Contract Number HO252038. The contract was initiated under the Metal and Nonmetal Health and Safety Research Program. It was administered under the technical direction of TCMRC with Mr. Guy Johnson acting as the Technical Project Officer. Mr. B.G. Horton was the contract administrator for the Bureau of Mines.

This report is a summary of the work recently completed as part of this contract during the period June 21, 1975 to June 30, 1976. This report was submitted by the authors on June 30, 1976.

The program was performed at The Ansul Company under the direction of Mr. Gene R. Reid, Program Manager; Mr. David L. Stockwell, Systems Project Engineer; and Mr. Richard J. Plog, Detection and Controls. Special acknowledgment should be given to the efforts of the following groups for their efforts towards the successful completion of this program:

- The coordination and performance of the data acquisition and data analysis phases by Midwest Research Institute of Kansas City, Missouri under the direction of D.M. Goldenbaum, PhD. and L.B. McDonald, PhD.

- The cooperation and assistance of the Hecla Mining Company during the performance of the underground fire test demonstration, particularly Mr. Claude Huber, Chief Mine Engineer.

- The assistance of Mr. Carl Christiansen, P.E., in the planning of the data acquisition and review of data acting as a program consultant.

- The efforts of Miss Debbie Smith in the preparation of this and other formal reports of this program.

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- D-2 APPLICATION FOR VARIANCE, LETTER MARCH 18, 1976
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1.0 INTRODUCTION

The object of the Bureau of Mines Research Contract HO252038 was to select the type of mobile, underground metal and nonmetal mining equipment which presented the greatest overall fire hazard; to develop a low cost, reliable, automatic fire protection system for that vehicle; and to demonstrate performance by on-vehicle fire tests in an underground mine. The contract period started on June 21, 1975 and extended through June 30, 1976.

As mine operators attempt to become more productive they tend to require more and more mechanized mobile equipment, and the equipment becomes larger more complex, and more expensive. Because of the increased density of underground vehicles and the hydraulics, fuels, and electric equipment associated with these vehicles the potential fire hazard is increasing.

Only a small percentage of the reported fires could not be controlled with hand portable fire equipment, but the safety of the mine, the high cost of the vehicle, and the production losses incurred by down time on the vehicle warrant the consideration of fixed fire protection systems. The controlled application of fire extinguishing agent to the critical areas provides more reliable protection than is available from reliance on hand portable equipment. The automatic fire protection system provides the following major advantages over manual systems:

- The operator is warned when the detection system senses a fire which may not be apparent to the operator.

- The vehicle is protected when the operator is not present or is incapacitated.

2.0 CONCLUSIONS AND RECOMMENDATIONS

2.1 Conclusions

- The load-haul-dump was identified as the class of mobile underground equipment found to constitute the greatest overall fire hazard.
- A low cost, reliable, automatic fire protection system was developed for a load-haul-dump vehicle, and demonstrated compliance with the established design requirements.
- The performance of the fire protection system was successfully demonstrated by on-vehicle tests in an underground mine.
- The system concept developed for the load-haul-dump vehicle is suitable for all types of diesel powered vehicles used in underground mines.
- The discharge of dry chemical agent in the underground mine environment did not create a serious obfuscation problem. Only the vehicle driver would have had vision temporarily obscured during the dry chemical discharges.

2.2 Recommendations

- A long-term validation program is required to demonstrate reliability in the underground mine environment. It is recommended that fire protection systems be installed on four types of vehicles in two mines and that system performance be monitored while the vehicles are in normal service for a period of at least one year.

3.0 DATA ACQUISITION PROCEDURES

3.1 Data Sources

During the data-gathering portion of the project, the following twelve (12) major sources of information were consulted:

(1) Bureau of Mines and MESA Staff
(2) Bureau of Mines Publications
(3) The Ansul Company
(4) MRI Staff
(5) Project Consultants
(6) MESA Reports
(7) General Literature
(8) Mine Company Management Staff
(9) Mine Safety Directors
(10) Mine Maintenance Staff
(11) Equipment Manufacturers
(12) Insurance Industry

	DATA SOURCE											
	1	2	3	4	5	6	7	8	9	10	11	12
MAJOR DATA REQUIREMENT	Bur. Mines & MESA Staff	Bur. Mines Reports	Ansul Staff	MRI Staff	Project Consultants	MESA Reports	General Literature	Mine Managers	Mine Safety Directors	Mine Maint. Staff	Equipment Manufacturers	Insurance Industry
Mine Equipment Fire Incident Descriptions	B	B				B	C	B	(A)	B		C
Mine Equipment Fire Incident Causes and Circumstances	C	B				B	C	C	(A)	B		B
Mine Equipment Operating Patterns and Environments	C			C	B			B	B	(A)		
Fire Control System Oper. & Use Patterns Environments								C	B	(A)	C	
Fire Control System Marketing Factors			B	B				(A)	C		B	

(A) – Best or Primary Source
B – Acceptable or Secondary Source
C – "Last Resort" or Corroborative Source

Figure 1 - Data Requirements x Sources Matrix

- Figure 1, the Data Requirements x Sources Matrix, shows the relative amounts of emphasis placed upon each of these alternative sources in obtaining data needed to satisfy each of the five major design input requirements.

3.2 Mines Sample Characteristics

This section summarizes the types and characteristics of the various mines visited during the data-gathering portion of the project.

(1) Total Mining Companies Visited: 18

(2) Total Individual Mine Sites Visited: 20

(3) Mine Size Ranges Represented: 3

a.	Sites with 5,000 tons per day (TPD) or less:	5	(28%)
b.	Sites with 5,000 - 10,000 TPD	8	(44%)
c.	Sites with 10,000 or more TPD	5	(28%)
	Total	18	(100%)

(4) Different Mining Techniques Represented

a.	Room and pillar or stoping	12	(60%)
b.	Cut and fill	3	(15%)
c.	Caving	5	(25%)
	Total	20	(100%)

Note: Several techniques used at some mines.

(5) Types of Commodities Represented: 15

		Mines
a.	Copper	5
b.	Fluorspar	1
c.	Gold	1

		Mines
d.	Gypsum	1
e.	Iron	2
f.	Lead	6
g.	Molybdenum	1
h.	Nickel	1
i.	Potash	2
j.	Silver	2
k.	Trona	3
l.	Tungsten	1
m.	Uranium	1
n.	Zinc	4
	Total	31

Note: Multiple commodities mined at some companies.

(6) States and Provinces Represented: 11

a. Arizona
b. Colorado
c. Idaho
d. Illinois
e. Iowa
f. Michigan
g. Missouri
h. New Mexico
i. South Dakota
j. Wyoming
k. Ontario (Canada)

(7) Estimated Production Values/Day

a.	Less than $100,000/Day	8	(44%)
b.	$100,000 - $500,000/Day	9	(50%)
c.	More than $500,000/Day	1	(6%)
	Total	18	(100%)

(8) Production Age in Years

a.	Less than 25 years	12	(66%)
b.	25 - 50 years	3	(17%)
c.	More than 50 years	3	(17%)
	Total	18	(100%)

(9) Estimated Total Miners Employed

a.	Less than 500	12	(66%)
b.	500 - 1,000	3	(17%)
c.	More than 1,000	3	(17%)
	Total	18	(100%)

Figure 2 indicates the individual states in which visited mines were located.

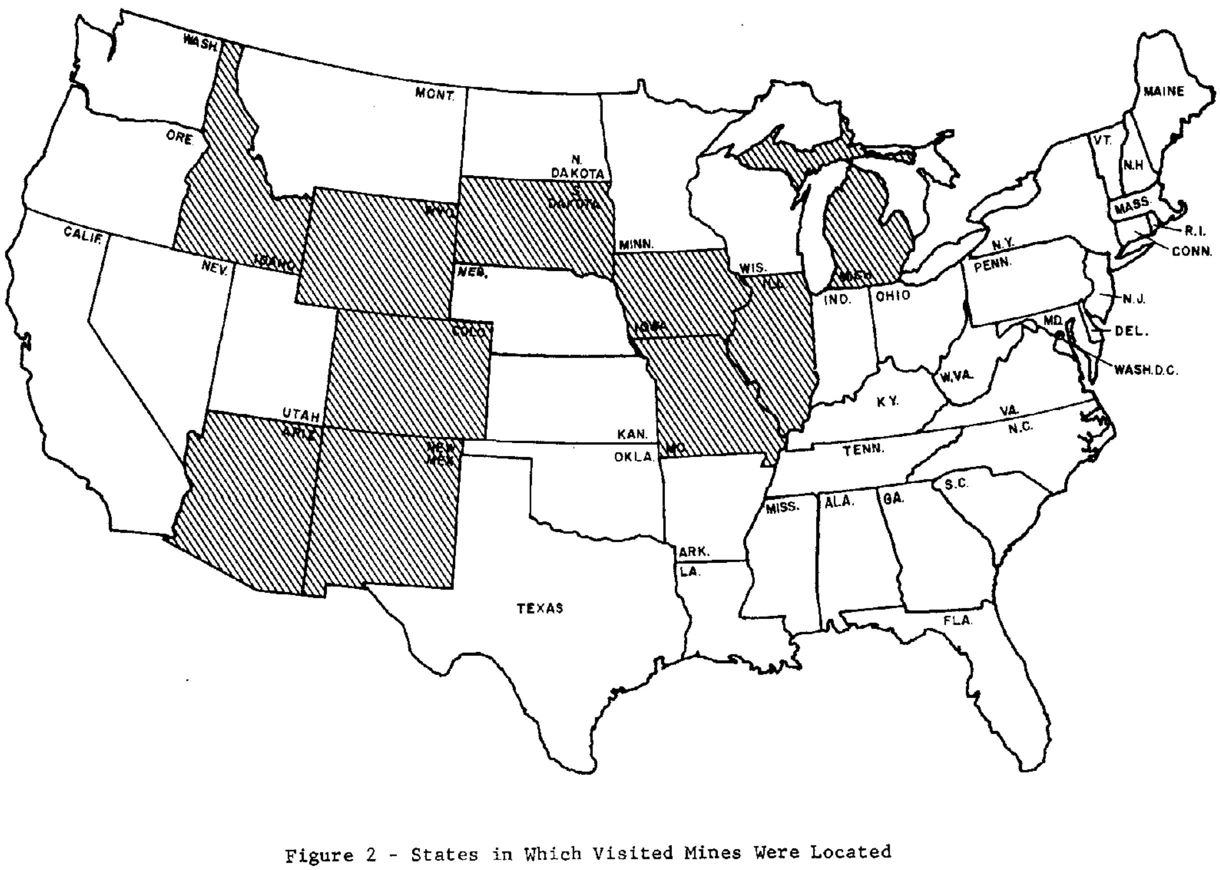


Figure 2 - States in Which Visited Mines Were Located
(Including Ontario, Canada)

3.3 Data Instruments

Six different data instruments were used in collecting the information needed to meet project data requirements. These instruments were used to summarize information obtained from appropriate data sources cited in Section 3.1.

These instruments, copies of which are provided in Appendix A, were:

(1) Mine description form
(2) Fire incident description interview summary sheet
(3) Fire hazard factor ratings interview summary form
(4) Equipment usage description interview summary sheet
(5) Maintenance procedures description interview summary form
(6) Market factor ratings interview summary sheet

3.4 Mine Visit Procedures

During a typical mine site visit, two interviewers would arrive at the mine head office at the beginning of a working day and would report to the individual (mine manager or safety director) who had helped arrange their visit. Because most mines conduct blasting operations in the afternoon, the tour of the mine would begin as early as possible in the morning to allow three to four hours underground.

During underground tours, interviewers would note the presence of any combustible materials observed in various parts of the mine. They also inspected vehicles between operations to check for apparent fuel or fluid leaks, for frayed wiring or hydraulic hoses, and for situations where fuel and heat sources were found in close proximity, looking for indications of possible past fires. Where appropriate, and with permission, photographs were taken of relevant portions of vehicles and mining operations.

Many mines maintained their entire maintenance staff underground. Interviews concerning vehicle maintenance procedures and relative fire hazard potentials for various types of vehicles were accordingly conducted, for the most part, during underground morning tours.

After the tour, the next step typically involved interviewing the mine's safety director about any fire incidents involving mobile vehicles at the mine over the last five years. Since few actual incidents were expected, safety directors were also asked subjectively to rate the relative fire hazard potential of various types of underground mobile vehicles, regardless of whether actual fires had occurred involving those types of vehicles in his mine.

Mine executives with authority to approve major equipment purchases were also interviewed briefly to determine acceptable purchase price and maintenance costs for an automatic fire control system. The desirability of various design features for such a system was also discussed and the executives' opinions recorded.

All interviews were conducted using an interview summary sheet, to help focus and standardize the questions, as well as to help simplify data recording. Following field interviews, interviewers would fill in appropriate portions of the data collection forms, based upon their observations and conversations during the day. In some instances rating forms were left with mining staff, who subsequently completed and returned such forms to MRI.

3.5 Literature Review Procedures

To assure inclusion of literature-reported underground vehicular fire incidents in the sample of incidents analyzed, a broad-based review was conducted of the non-coal mining fire literature. This literature review was carried out principally using the publications and materials available at, or through, the Linda Hall Library of Science and Technology, at Kansas City, Missouri. Other literature sources tapped included those at Midwest Research Institute itself, MESA, and the Bureau of Mines offices at Bruceton, Minneapolis, and Denver.

Incidents of relevance to the present data-collection and analysis effort were found, for example, in Bureau of Mines and MESA fire reports, assorted conference proceedings, in-house publications of larger mining companies and equipment manufacturers, and in a wide variety of technical and industry-related journals. In several instances, the same fire incidents were found to be reported in different articles, papers, and reports, in addition to being described to project researchers during mine visits. Foreign journals (principally French) were also found to contain descriptions of relevant fire incidents in non-coal underground mines.

Where incidents uncovered through the literature review were described in sufficient detail to allow inclusion in the study sample, a Fire Incident Description Interview Summary Sheet was filled out for each such incident. Data on these fire incidents were then included with the data gathered during mine site visits, in performing the required statistical analyses.

A bibliography of sources found most relevant to the present study is included in Appendix B of this report.

3.6 Description of Analysis Data Base

The data base which resulted from the acquired data included the following:

(1) Descriptive data on 21 different mines (including those visited during the study), representing 31 different ores mined and four different mining techniques, employing over 9,000 mine workers, and located in nine different states and one Canadian province.

(2) Analyses of the characteristics and causes of 55 actual vehicle-related fire incidents, covering over 20 different types of mobile underground mining equipment over a 25-year period (1950-75).

(3) Information gathered through review of over 50 relevant domestic and foreign publications and articles, including MESA reports.

In the process of building this study base, a total of 173 data forms were filled out by study team members, and statistical computations were performed using electronic desk calculators.

4.0 ANALYSIS OF DATA

In this section the conclusions regarding each of the major data requirements (Figure 1) are summarized, and the analyses on which the conclusions are based follow in the subparagraphs.

(1) Vehicle Hazardousness Analysis

The load-haul-dump was identified as the class of mobile underground equipment found to constitute the greatest overall fire hazard.

(2) Fire Incident Characteristics Analysis

Typical fires associated with load-haul-dumps and front-end loaders are of less than ten minutes duration, involve the burning of hydraulic fluid and/or wiring insulation, and are principally caused by infrequent or improper maintenance, rather than, e.g., by operator error.

In load-haul-dump (LHD) fires, the following parts of the vehicles constituting the greatest overall fire hazards (ranked from highest to lowest) were:

a. Hydraulic hoses
b. Engine compartment
c. Wiring
d. Battery cable
e. Compressor hoses

LHD fires were typically within the driver's normal field of view at outbreak (62% of incidents). The operator typically had no difficulty exiting the vehicle when aware of the fire, and was himself cited as a causal or contributing factor for the fire in only 12% of the LHD fire incidents. In those two incidents where operator error was cited, one involved throwing combustible rags into an oil sump. In the other, the operator lost control of the vehicle, jumped or fell out, was run over by the vehicle and killed, and the vehicle subsequently crashed into the wall and burned.

LHD operators attempted to extinguish the fire 96% of the time, left the vehicle 1% of the time, and were not present 3% of the time. When attempting to extinguish the fire, the operators utilized one or more portable extinguisher in 96% of the attempts and were successful 96% of these times. In the 4% of the cases involving installed manual systems, one system effectively extinguished the fire and the other system (of unknown French origin) failed to operate. Only 2% of the drivers turned off the engine before leaving the vehicle.

Front-end loader (FEL) fires, in comparison, were found to involve the following parts of the vehicle (ranked from highest to lowest in hazardousness):

a. Compressor hose
b. Driver compartment
c. Engine compartment and hydraulic hoses
d. Battery cable
e. Brakes

FEL fires were as often within (50%) as they were beyond the operator's normal field of view at outbreak. Again, the driver had no reported difficulty exiting the vehicle once aware of the fire. In no case investigated did operator error play any discernible causal or contributory role in causing FEL fires.

FEL operators attempted to extinguish the fire 85% of the time, and left the vehicle 15% of the time. When they did attempt to extinguish the fire (mostly minor ones) they were successful in all of the cases reported. The drivers turned off the engine before leaving 25% of the time.

(3) Vehicle Operating Environments Analysis

The mines in which mobile underground equipment of the LHD and FEL type typically operate were found to have average temperatures of about 65°F, humidities ranging up to 100% (with an average of 78%), and tunnel heights ranging from 3.5 feet up to an average of about 11.6 feet. LHD's and FEL's are typically subjected to little stationary vibration, but they are used on underground pathways that range from rough to pothole-infested, and encounter shocks ranging from bottoming out and lurching, to shocks that produce impact noises.

(4) Vehicle Condition and Maintenance Procedures Analysis

In addition to the above environmental conditions, any automatic fire control system (AFCS) installed on LHD's and/or FEL's would need to be able to survive being coated with hydraulic fluid and lubricant from hose leaks, and with muck and mud from the mine itself. In addition, any AFCS designed for use on these types of hazardous vehicles would in some mines need to withstand corrosive chemicals generated as part of the mining process, especially sulfuric acid, sulfides, and sulfates. Finally, during typical maintenance procedures for FEL's and LHD's, any AFCS would be subjected regularly to high-pressure steam and to solvents designed to help clean oil-based coatings from the vehicles.

(5) System Marketing Factors Analysis

Analysis of the results of interviews with mine officials indicated that the following AFCS characteristics (listed in order from most desirable, downwards) were considered important in deciding whether to purchase any AFCS made available:

a. System reliability (most important)
b. Ease of maintenance
c. Frequency of maintenance
d. System purchase price
e. Maintenance cost for system
f. Operator training requirements
g. System location on vehicle
h. Ease of installation

Other factors entering into (hypothetical) decisions to purchase the AFCS to be developed were:

a. Replacement/reorder time for vehicle (most important)
b. Replacement cost of vehicle
c. Duty cycle of vehicle
d. Lost production costs
e. Probability of fire on vehicle
f. Insurance rate reductions

In addition, mine officials indicated they would be willing to pay, on the average, approximately 7% of the purchase price of the vehicle itself in buying such an AFCS, provided the AFCS had a reliability rate of 95% or better. They indicated willingness to pay an average of $140 per month to maintain such an AFCS in working order, providing the system would last at least eight years, on equipment whose life expectation might average 9.5 years.

4.1 Vehicle Hazardousness Analysis

In this section, explanations are given of the methodology followed in identifying the most hazardous kinds of mobile underground mining equipment, and the actual statistical computations involved are presented in a series of data tables.

At the outset, a tally was made of each type of reported fire incident associated with each of the twenty (20) different types of equipment considered. The results of this initial tally are given in Table 1, where it is seen that 18 of the types of incidents were attributed to load-haul-dumps, 12 to locomotives and cars, 8 to haulage trucks, 6 to front-end loaders, and less than three incidents each to the remaining 16 types of underground equipment considered. During the survey, estimates were also obtained of the number of times per year each type of incident occurred. Using these estimates of the number of similar incidents, it was found that locomotives had by far the greatest raw number of fire incidents (109.2 incidents per year), with load-haul-dumps second, at 17.8 incidents per year.

TABLE 1

ESTIMATED TOTAL FIRE INCIDENTS PER YEAR, PER TYPE EQUIPMENT

Vehicle Type	Total Types of Fire Incidents Investigated (All visited mines, all sources, all years)	Estimated Actual Total Similar Fire Incidents Per Year
Load-Haul-Dump	18	17.8
Locomotive/Cars	12	109.2
Haulage Truck	8	6.1
Front-End Loader	6	4.0
Other[a]	≤ 3 each	≤ 0.5 each

a/ Nine types of mobile equipment, each with three or fewer incidents reported.

Combining all such estimated incidents per year into one pool of incidents, Figure 3 shows the percentages of estimated total fire incidents per year attributed to each of the four types of vehicles that were themselves most fire-involved: locomotives/cars, load-haul-dumps, haulage trucks, and front-end loaders. Locomotives/cars accounted for the vast majority of the fires per se, 78.2% of the estimated total number of fires that occur in the mines visited, during any given year.

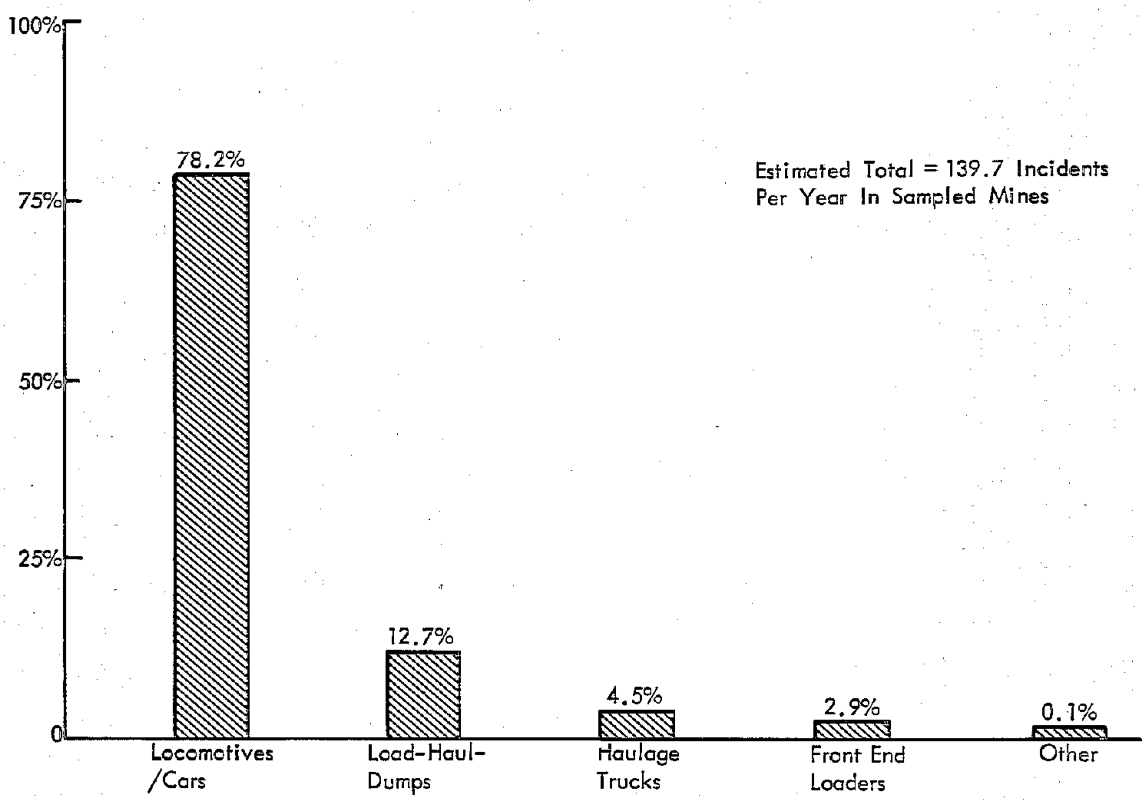


Figure 3 - Percentage of Estimated Total Fire Incidents per Year Involving Different Types of Vehicles

But number of fires by itself cannot reflect the true hazardousness of a particular type of vehicle. It turns out, for example, that locomotive fires are generally very brief, of limited extent, easily extinguished, and confined largely to the "nuisance" level in underground mines. Load-haul-dump fires, on the other hand, while occurring less frequently, tended to be comparatively more severe and have greater impacts upon mine production.

These differences in the extent, impact, and dangerousness of vehicle-associated fires needed to be taken into account, in order to objectively identify the most "hazardous" type of underground vehicle. Three measures were defined, on the basis of which, the overall hazardousness of a particular type of vehicle could be estimated. These were: projected costs of fires that will be associated with the type of vehicle in 1980; the hazardousness of the fire incidents likely to be associated with the type of vehicle in 1980; and the subjective ratings of "hazardousness" given each type of vehicle by mining officials (assumed to be unchanged in 1980).

To identify the type of vehicle that is most hazardous in an overall sense, each type of vehicle was first ranked according to its "hazardousness" on each of the above three measures, and the average rankings received by each type of vehicle were computed.

Table 2 shows the results of these computations, and gives the final average "hazardousness" rankings of the four types of underground vehicles found most generally to be associated with fires. The type of mobile underground mining equipment identified as most hazardous was the load-haul-dump, with an average ranking on the three measures of 1.6. The highest possible ranking, it should be noted, would have been 1.0 and the lowest 4.0. Front-end loaders came second, with an overall ranking of 2.3, then haulage trucks with 2.6, and finally locomotives with 3.5.

TABLE 2

CALCULATION OF OVERALL HAZARDOUSNESS RATINGS FOR FOUR TYPES OF FIRE-INVOLVED VEHICLES

Vehicle Type	1980 Fire Cost Projection ($)	Rank	1980 Incident Hazardousness Rating	Rank	1980 Vehicle Hazardousness Rating	Rank	Average Factor Ranking	Final Ranking
Load-Haul-Dumps	882,063	1	2,030.7	1	7.9	3	1.6	1
Front-End Loaders	148,428	3	821.6	3	6.1	1	2.3	2
Haulage Trucks	121,806	4	1,390.2	2	6.2	2	2.6	3
Locomotives	148,910	2	257.1	4	9.4	4	3.5	4

Tables and figures comprising the remainder of this section are intended to show the sources of, and elaborate upon, the results summarized in Table 2.

First, computations of the projected total fire costs for each type of vehicle in 1980 are given in Table 3. For each of the four types of vehicles of interest, estimated total fire costs per year (over the past five years) were computed. The results of these computations are given in Column 1 of Table 3. The actual computations of estimated total fire costs per year for each type of vehicle are given in Tables 4 through 7, respectively, which will be discussed later.

TABLE 3

FIRE COSTS PROJECTIONS FOR 1980 IN SAMPLED MINES

Vehicle Type	(1) Estimated Total Fire Costs Per Year	(2) Total Pieces This Type Equipment in Sampled Mines	(3) Estimated Total Fire Costs Per Vehicle Per Year (1) ÷ (2)	(4) Vehicle Population Growth Factor for 1980	(5) 1980 Total Fire Costs Projection (1) x (4)
Load-Haul-Dumps	$294,021	239	$1,230	3.0	$882,063
Front-End Loaders	42,408	88	481	3.5	148,428
Haulage Trucks	40,602	142	285	3.0	121,806
Locomotives/Cars	297,821	369	807	0.5	148,910

Next, (Column 2 of Table 3) the total pieces of each type equipment is given. This total reflects the number of pieces of these types of equipment found actually to be in operation in the mines visited during the survey, and included 239 load-haul-dumps, 88 front-end loaders, and so on.

Column 3 of this table, an estimate of the total fire costs per vehicle per year, was obtained by dividing total fire costs per year by total pieces of that type equipment in operation.

Column 4, the vehicle population growth factor for 1980, is a subjective estimate of the increase or decrease in size of the current number of vehicles of this type over the next five years (1975-80), and was obtained from representatives of the equipment manufacturing firms contacted during the study.

Finally, the last column of Table 3--the 1980 total fire costs projections per type of vehicle--was obtained by multiplying the estimated total fire costs per year (Column 1) by the vehicle population growth factor for 1980 (Column 4). It is assumed in this computation that total fire costs associated with a particular type of vehicle will grow linearly with an increase in the number of vehicles of that type. These figures are the ones given in Table 2.

Continuing further with an explanation of the methodology by which 1980 fire cost projections were obtained, Tables 4 through 7 show how the costs of actual fire incidents were computed, for each of the four types of vehicles of greatest interest. On Table 4, for example, it is seen that costs were estimated for each of 16 different reported fire incidents associated with load-haul-dumps. The six numbered columns comprising these four tables are, respectively:

Column 1 - Estimated Human Costs: It is assumed to be $50,000 per fatality, and $1,000 per injury or the actual injury costs, whichever was higher.

Column 2 - Estimated Vehicle Repair/Replacement Costs: Representing the combined total of vehicle repair and vehicle replacement costs associated with the particular incident, repair costs were based upon an estimated $8 per man-hour of repair time; replacement costs were based upon the current price of the type of vehicle (e.g., $160,000 per load-haul-dump).

Column 3 - Estimated Lost Production Costs: Representing the combined total of production losses due to vehicle downtime, and production losses due to mine shutdown or slowdown resulting from the fire incident.

Losses due to vehicle downtime were assumed to be the product of the estimated value of one hour of that type vehicle's production, and the estimated total number of hours the vehicle was down <u>beyond</u> the amount of time the mine itself was down (if the mine was shut down as a result of the incident). This latter adjustment was intended to help avoid attributing double costs to the same amount of vehicle downtime.

In turn, the estimated value of a vehicle's production hour was based upon the hourly production value for the mine, divided by the estimated total pieces of this type equipment (or its functional equivalent) in operation in the mine involved. For example, load-haul-dumps and front-end loaders were assumed to be functionally equivalent, so that when one was

TABLE 4

COSTS ASSOCIATED WITH LOAD-HAUL-DUMP FIRES

Fire Incident No.	(1) Estimated Human Costs	(2) Estimated Vehicle Repair/ Replacement Costs	(3) Estimated Lost Production Costs	(4) Estimated Total Incident Costs (1) + (2) + (3)	(5) Estimated Number of Similar Incidents Per Year Over 5-Year Period	(6) Total Estimated Fire Costs Per Year for This Type Incidents (4) x (5)
1	-	$ 8	$ 1,087	$ 1,095	0.20	$ 219
2	-	8	1,052	1,060	0.67	710
3	-	8	774	782	3.00	2,346
4	-	17	53,328	53,345	0.20	10,669
5	-	34	1,053	1,087	6.00	6,522
6	-	8	353	361	4.00	1,444
7	-	34	1,331	1,365	0.20	273
8	-	17	1,067	1,084	0.20	217
9	-	8	555	563	2.00	1,126
10	-	8	555	563	0.20	112
11	-	8	3,011	3,019	0.20	604
12	-	34	11,108	11,142	0.20	2,228
13	$100,000	160,000	999,936	1,259,936	0.20	251,987
14	-	34	111,104	111,138	0.20	2,228
15	-	18	33,332	33,350	0.20	6,670
16	-	-	33,332	33,332	0.20	6,666
Total	$100,000	$160,244	$1,252,978	$1,513,222	17.87	$294,021

TABLE 5

COSTS ASSOCIATED WITH FRONT END LOADER FIRES

Fire Incident No.	(1) Estimated Human Costs	(2) Estimated Vehicle Repair/ Replacement Costs	(3) Estimated Lost Production Costs	(4) Estimated Total Incident Costs (1) + (2) + (3)	(5) Estimated Number of Similar Incidents Per Year Over 5-Year Period	(6) Total Estimated Fire Costs Per Year for This Type Incidents (4) x (5)
1	-	$ 8	$ 8,436	$ 8,444	0.2	$ 1,688
2	-	34	31,764	31,798	0.2	6,359
3	-	-	660	660	0.2	132
4	$1,000	34	151,664	151,698	0.2	30,359
5	-	51	3,597	3,648	0.2	729
6	-	17	1,030	1,047	3.0	3,141
Total	$1,000	$144	$197,151	$197,295	4.0	$42,408

TABLE 6

COSTS ASSOCIATED WITH HAULAGE TRUCK FIRES

Fire Incident No.	(1) Estimated Human Costs	(2) Estimated Vehicle Repair/ Replacement Costs	(3) Estimated Lost Production Costs	(4) Estimated Total Incident Costs (1) + (2) + (3)	(5) Estimated Number of Similar Incidents Per Year Over 5-Year Period	(6) Total Estimated Fire Costs Per Year for This Type Incidents (4) x (5)
1	-	$ 8	$ 4,218	$ 4,226	0.6	$ 2,535
2	-	8	1,204	1,212	0.2	242
3	-	8	1,204	1,212	2.5	3,030
4	-	68	3,606	3,674	0.2	734
5	-	17	1,230	1,247	2.0	2,494
6	-	34	2,410	2,444	0.2	488
7	-	8	5,707	5,715	0.2	1,143
8	-	50,000	99,984	149,984	0.2	29,936
Total	-	$50,151	$119,563	$169,714	6.1	$40,602

TABLE 7

COSTS ASSOCIATED WITH LOCOMOTIVES/CARS FIRES

Fire Incident No.	(1) Estimated Human Costs	(2) Estimated Vehicle Repair/ Replacement Costs	(3) Estimated Lost Production Costs	(4) Estimated Total Incident Costs (1) + (2) + (3)	(5) Estimated Number of Similar Incidents Per Year Over 5-Year Period	(6) Total Estimated Fire Costs Per Year for This Type Incidents (4) x (5)
1	-	$ 17	$ 787	$ 804	2.0	$ 1,608
2	-	34	2,750	2,784	2.0	5,574
3	-	17	-	17	2.0	34
4	-	68	2,750	2,818	2.0	5,636
5	-	17	839,988	840,005	0.2	168,001
6	-	8	-	8	63.0	504
7	-	68	13,750	13,818	0.2	2,763
8	-	34	2,150	2,184	0.2	437
9	-	17	295	312	0.2	62
10	-	17	3,087	3,104	35.0	108,640
11	-	34	13,986	14,020	0.2	2,804
12	-	34	8,675	8,709	0.2	1,742
13	-	8	-	8	2.0	16
Total	-	$373	$888,218	$888,591	109.2	$297,821

down, another could temporarily take its place. The hourly production value for the mine, finally, was simply the daily production value of the mine (estimated by the project consultant where otherwise unavailable), divided by the product of the number of shifts and the estimated duration of the fire incident in hours, i.e., divided by the proportion of a single shift, or the number of shifts, assumed lost due to the fire.

Mine shutdown costs, the second major component of this third measure, was estimated by multiplying the same hourly production value for the mine used above, by the reported number of hours the mine was shut down as a result of the fire incident in question.

It should be noted that a special adjustment was made in the case of locomotive fires. Locomotive-associated fires were assumed to have a considerably less direct impact upon mine production than did fires attributed to the other three types of vehicles, because locomotives generally operate in "batch mode." A locomotive can be out of service for some time, while production goes on at the mine faces; it can presumably be repaired during its frequent "slack" periods, awaiting the next full load to be taken out of the mine. For this reason, three hours were subtracted from the estimated number of hours locomotives were assumed to be in repairs, before multiplying by the cost per production hour lost.

Column 4 - Estimated Total Incident Costs: These were simply the sum of the three above costs per incident.

Column 5 - Estimated Number of Similar Incidents Per Year Over a Five-Year Period: This was obtained subjectively from mine officials describing the incident in question.

Column 6 - Estimated Total Fire Costs Per Year for this Type Incident: Finally, they were computed as the product of the total incident costs (Column 4 on the tables) and the estimated number of similar incidents per year (Column 5). It should be observed that, in many cases, costly incidents were estimated to happen infrequently, and *vice versa*. This was especially true in the case of locomotive fires (Table 7).

. Figures 4, 5, and 6 illustrate some of the findings generated above. Figure 4 shows that there will probably be more load-haul-dumps (717) in the sampled mines than there will be of any of the remaining three types of equipment of interest (with locomotives, 184, representing the fewest in number). Figure 5, again, shows load-haul-dumps to have the greatest fire costs per vehicle per year in the sampled mines, followed by locomotives, with the second greatest estimated fire costs. But Figure 6, reflecting the projected situation in 1980, puts load-haul-dumps considerably out in front of locomotives, due to the fact that locomotives are being phased out (a growth factor of 0.5), and that load-haul-dumps will triple in number (a growth factor of 3.0).

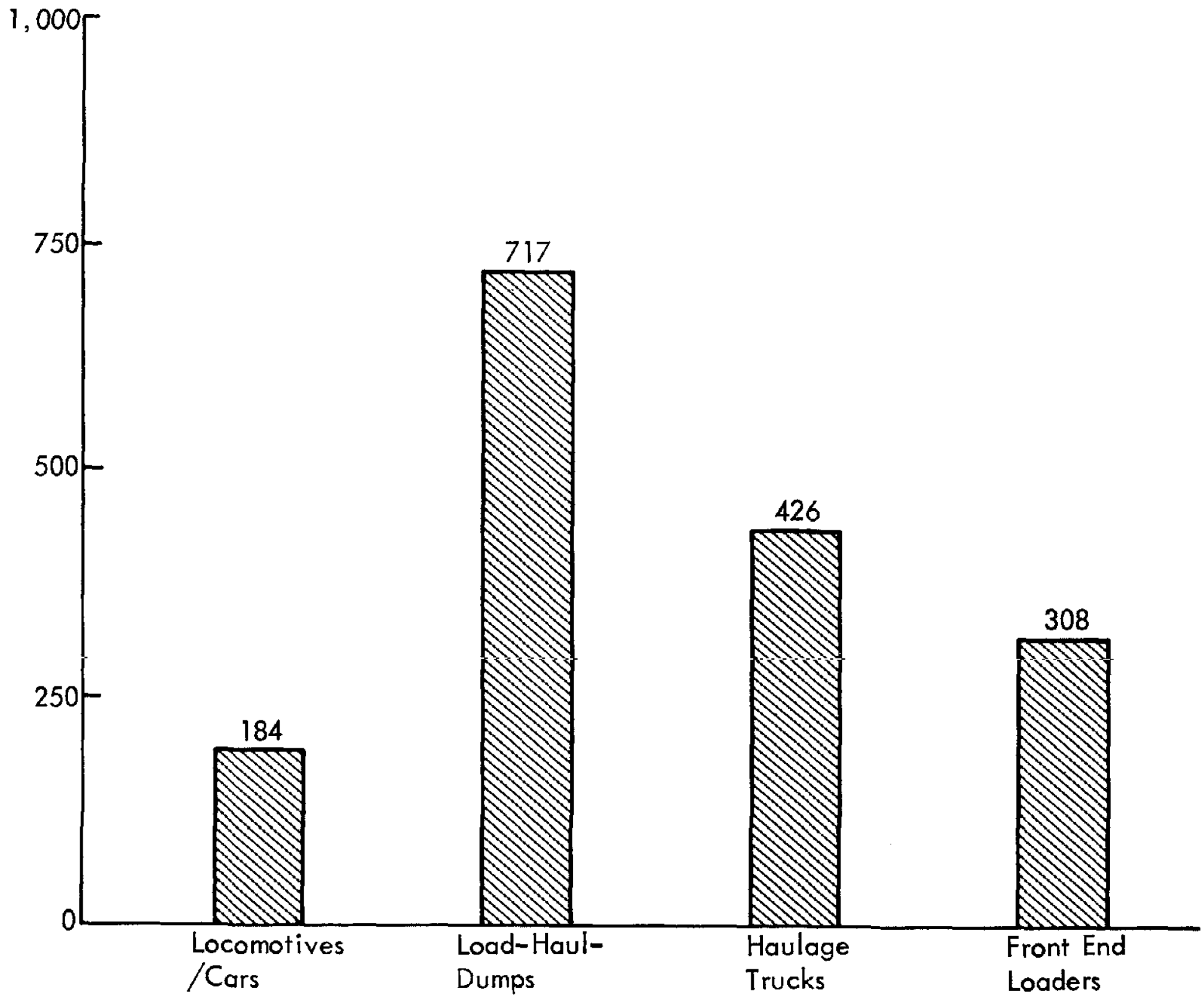


Figure 4 - Estimated Total Vehicles in Sampled Mines in 1980

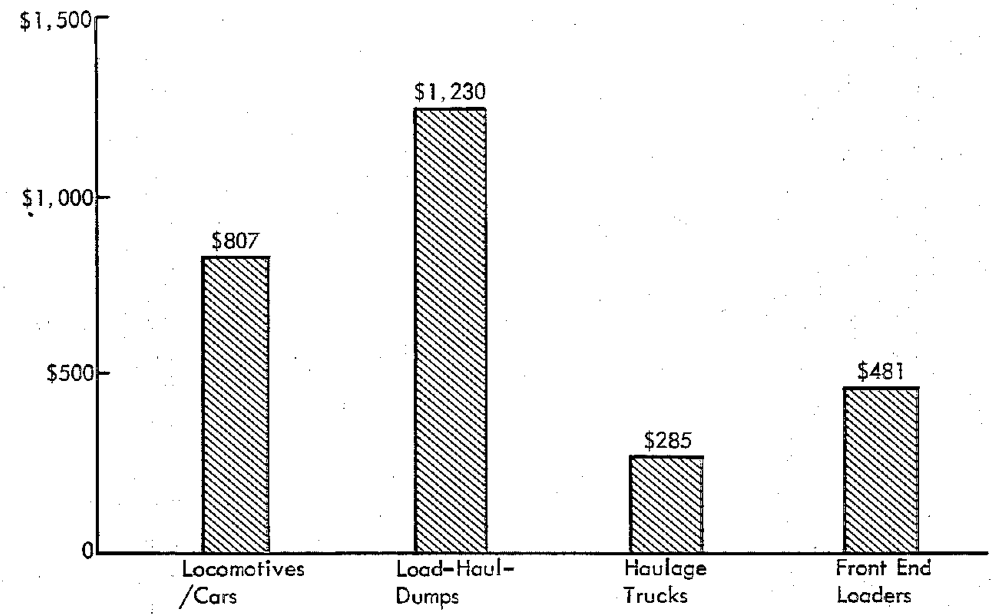


Figure 5 - Estimated Fire Costs per Vehicle per Year in Sampled Mines

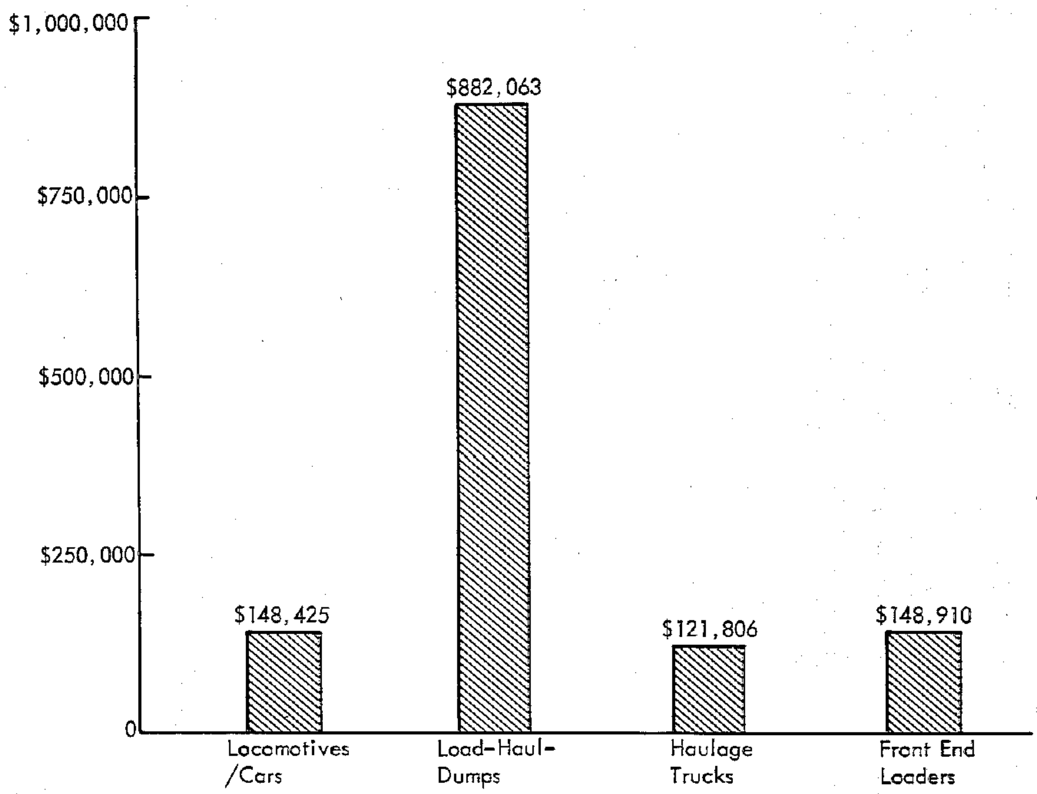


Figure 6 - Estimated Total Projected Fire Costs in 1980 in Sampled Mines

. Returning to Table 2, it will be recalled that the second of the three major "hazardousness" measures employed was the estimated total hazardousness of the fire incidents likely to be associated with each of the four types of vehicles in 1980. Table 2 shows that front-end loaders, instead of load-haul-dumps, ranked first in this projected incident hazardousness (whereas load-haul-dumps had ranked first in the earlier measure, projected costs).

As indicated on Table 8, the relative hazardousness of all projected 1980 fire incidents for each of the four types of vehicles was computed by multiplying the total weighted overall fire hazard rating (Column 1) by the estimated total pieces of the type of equipment in 1980 (Column 8). Remaining columns in Table 8 provide other statistics of interest, but only the figures entered under Column 9 were used in making final determinations of the relative hazardousness of the four types of vehicles in question.

TABLE 8

INCIDENTS HAZARDOUSNESS PROJECTIONS FOR 1980

Vehicle Type	(1) Total Weighted Overall Fire Hazard Rating (all incidents, all mines)	(2) Estimated Total Incidents in Sampled Mines Over 5-year Period	(3) Average No. of Incidents Per Year (all mines) (2) ÷ 5	(4) Total Pieces of This Type Equipment (all mines)	(5) Average No. of Incidents per Year per Vehicle (3) ÷ (4)	(6) Average Calculated Hazard Rating for Incident Per Vehicle Per Year (1) ÷ (5) ÷ 100	(7) Vehicle Population Growth Factor For 1980	(8) Estimated Total Pieces This Type Equipment in 1980 (4) x (7)	(9) 1980 Weighted Total Hazardousness Rating (1) x (8) ÷ 100
Load-haul-dumps	283.22	89	17.9	239	.075	37.8	3.0	717	2,030.7
Front end loaders	266.75	20	4.0	88	.045	59.3	3.5	308	821.6
Haulage trucks	326.35	30.5	6.1	142	.045	75.9	3.0	426	1,390.2
Loco-motives/Cars	139.73	546	109.2	369	.296	4.7	0.5	184	257.1

Among the statistics of possible interest are those graphed in Figure 7, the average calculated hazard ratings per incident per vehicle per year in sampled mines. This figure shows that haulage trucks, rather than load-haul-dumps or front-end loaders, tend to have the most hazardous fires *per se*. That is, the individual fire incidents associated with haulage trucks are rated, using the methods that will be described below, as more dangerous on an individual basis than were the fires associated with the other types of vehicles. As we shall see, however, when weighted for the numbers of incidents occurring, and the number likely to occur as a result of vehicle population growth in the future, haulage trucks must take second place to load-haul-dumps (Figure 8).

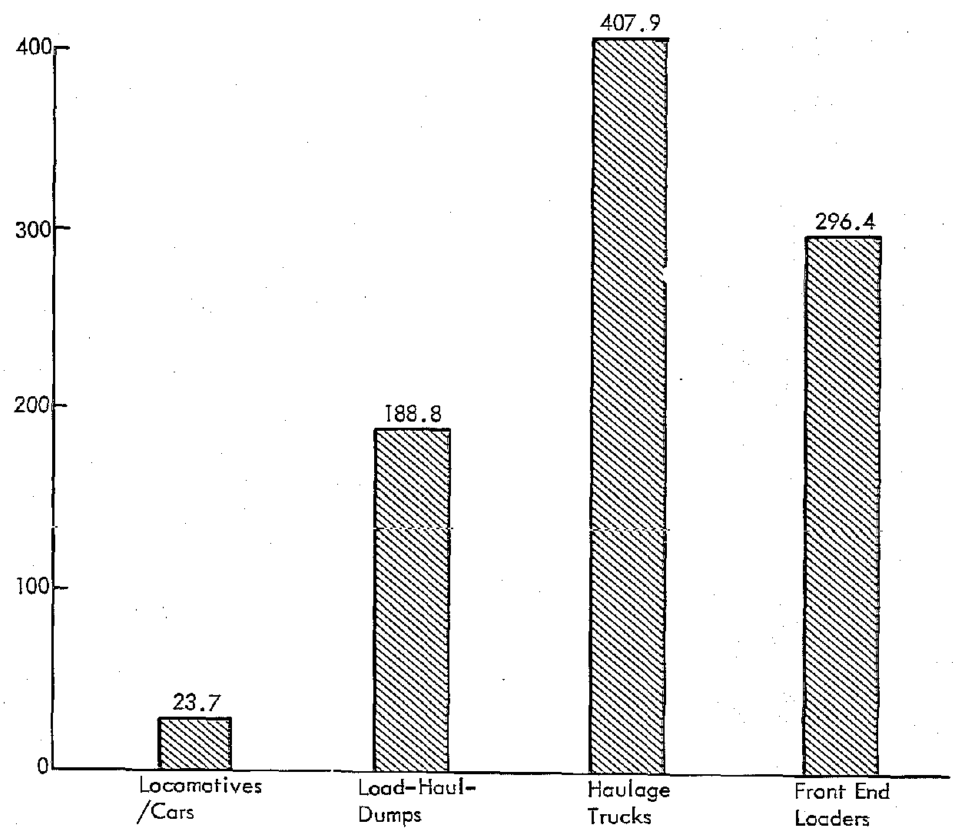


Figure 7 - Average Calculated Hazard Ratings per Incident per Vehicle per Year in Sampled Mines

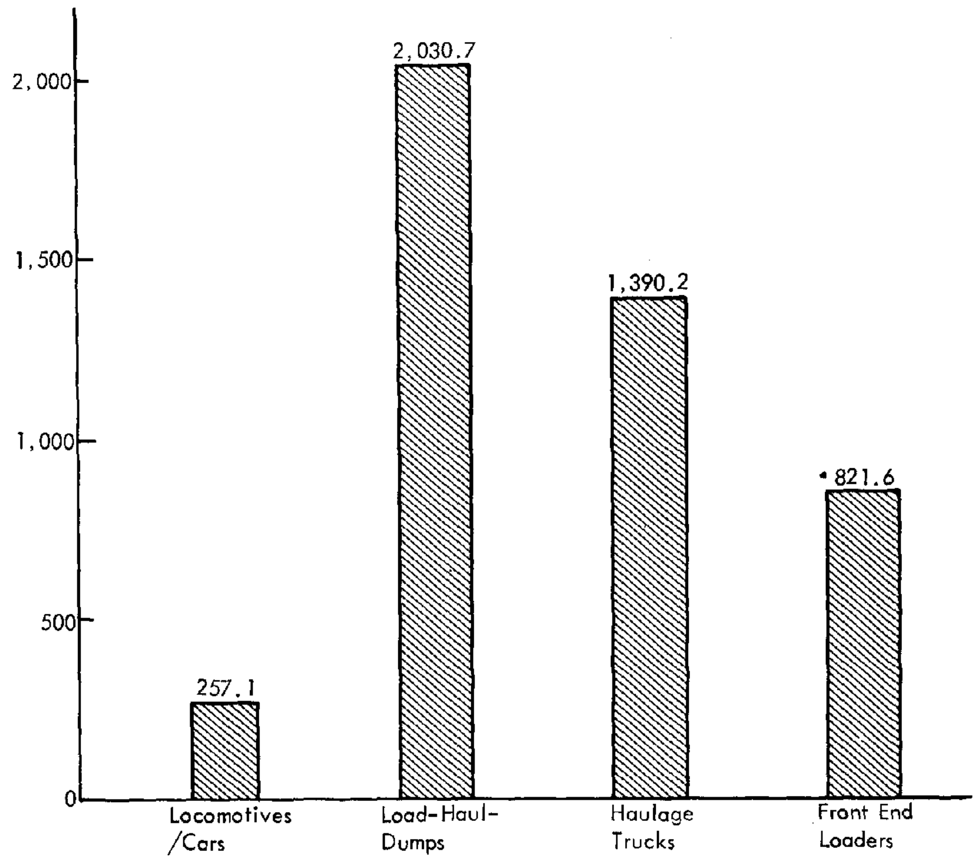


Figure 8 - 1980 Weighted Total Hazardousness Rating

Tables 9 through 12, as above, show how the actual hazardousness ratings were computed for each incident associated with each of the four types of vehicles, repectively. The eight numbered columns comprising each of these four computational tables are, respectively:

Column 1 - Severity Rating for Operator, which had a value of 1 if the fire was determined to have been slight (i.e., little or no danger of the operator being burned, and no problem exiting the vehicle or immediate area); a value of 2 if the fire was rated as moderate (i.e., operator had some chance of being burned, but had no problem exiting vehicle or immediate area); and a value of 3 if judged to be severe (i.e., operator was very likely to be burned or was burned, and problems existed in his exiting the vehicle or immediate area).

TABLE 9

CALCULATION OF INCIDENT HAZARDOUSNESS RATINGS FOR LOAD-HAUL-DUMP FIRES

Fire Incident Number	(1) Severity Rating for Operator	(2) Severity Rating for Other Miners	(3) Estimated Proportion of Miners Exposed to Danger	(4) Weighted Severity for Other Miners (2) x (3)	(5) Overall Severity for Operator and Other Miners (1) + (4)	(6) Estimated Total Incidents of This Type In Mine Over 5-Years	(7) Percentage of Total Incidents Represented (Total = 100)	(8) Weighted Overall Fire Hazard Rating For This Incident (5) x (7)
1	2	3	0.65	1.95	3.95	1	1.0	3.95
2	3	3	0.55	1.65	4.65	3	3.0	13.95
3	1	1	0.55	0.55	1.55	15	15.0	23.25
4	1	1	0.25	0.25	1.25	1	1.0	1.25
5	2	3	0.65	1.95	3.95	30	30.0	118.50
6	1	3	0.45	1.35	2.35	20	20.0	47.00
7	1	3	0.65	1.95	2.95	20	20.0	47.00
8	1	1	0.42	0.42	1.42	1	1.0	1.42
9	1	1	0.42	0.42	1.42	2	2.0	2.84
10	1	3	0.42	1.26	2.26	1	1.0	2.26
11	1	1	0.45	0.45	1.45	1	1.0	1.45
12	1	3	0.05	0.15	1.15	1	1.0	1.15
13	3	5	0.45	2.25	5.25	1	1.0	5.25
14	3	5	0.45	2.25	5.25	1	1.0	5.25
15	2	3	0.65	1.95	3.95	1	1.0	3.95
16	2	5	0.55	2.75	4.75	1	1.0	4.75
							Total	283.22

TABLE 10

CALCULATION OF INCIDENT HAZARDOUSNESS RATINGS FOR FRONT END LOADER FIRES

Fire Incident Number	(1) Severity Rating for Operator	(3) Severity Rating for Other Miners	(3) Estimated Proportion of Miners Exposed to Danger	(4) Weighted Severity for Other Miners (2) x (3)	(5) Overall Severity for Operator and Other Miners (1) + (4)	(6) Estimated Total Incidents of This Type in Mine Over 5-Years	(7) Percentage of Total Incidents Represented (Total = 100)	(8) Weighted Overall Fire Hazard Rating For This Incident (5) x (7)
1	2	3	0.65	1.95	3.95	1	5	19.75
2	2	3	0.65	1.95	3.95	1	5	19.75
3	1	1	0.65	0.65	1.65	1	5	8.25
4	3	5	0.65	3.25	6.25	1	5	31.25
5	2	3	0.55	1.65	3.65	1	5	18.25
6	1	3	0.42	1.26	2.26	15	75	169.50
							Total	266.75

TABLE 11

CALCULATION OF INCIDENT HAZARDOUSNESS RATINGS FOR HAULAGE TRUCK FIRES

Fire Incident Number	(1) Severity Rating for Operator	(2) Severity Rating for Other Miners	(3) Estimated Proportion of Miners Exposed to Danger	(4) Weighted Severity for Other Miners (2) x (3)	(5) Overall Severity for Operator and Other Miners (1) + (4)	(6) Estimated Total Incidents of This Type in Mine Over 5-Years	(7) Percentage of Total Incidents Represented (Total = 30)	(8) Weighted Overall Fire Hazard Rating for This Incident (5) x (7)
1	1	1	0.45	1.45	2.45	3	10.0	24.50
2	1	3	0.80	2.40	3.40	1	3.3	11.22
3	1	1	0.80	0.80	1.80	12	40.0	72.00
4	1	5	0.65	3.25	4.25	1	3.3	14.03
5	1	3	0.65	1.95	4.95	10	33.3	164.83
6	1	3	0.65	1.95	2.95	1	3.3	9.73
7	2	3	0.45	1.35	3.35	1	3.3	11.06
8	3	5	0.55	2.75	5.75	1	3.3	18.98
							Total	326.35

CALCULATION OF INCIDENT HAZARDOUSNESS RATINGS FOR LOCOMOTIVES/CARS FIRES

Fire Incident Number	(1) Severity Rating for Operator	(2) Severity Rating for Other Miners	(3) Estimated Proportion of Miners Exposed to Danger	(4) Weighted Severity for Other Miners (2) x (3)	(5) Overall Severity for Operator and Other Miners (1) + (4)	(6) Estimated Total Incidents of This Type in Mine Over 5-Years	(7) Percentage of Total Incidents Represented (Total = 521)	(8) Weighted Overall Fire Hazard Rating for This Incident (5) x (7)
1	1	3	0.45	1.35	2.35	10	0.019	0.045
2	2	3	0.55	1.65	3.65	2	0.004	0.015
3	1	1	0.65	0.65	1.65	10	0.019	0.031
4	1	3	0.65	1.95	2.95	2	0.004	0.012
5	3	5	0.65	3.25	6.25	1	0.002	0.012
6	1	1	0.42	0.42	1.42	315	60.458	85.850
7	1	3	0.15	0.45	1.45	1	0.002	0.003
8	1	3	0.20	0.60	1.60	1	0.002	0.003
9	1	3	0.20	0.60	1.60	1	0.002	0.003
10	1	3	0.20	0.60	1.60	175	33.588	53.741
11	1	3	0.45	1.35	2.35	1	0.002	0.005
12	1	3	0.80	2.40	3.40	1	0.002	0.007
13	1	1	0.42	0.42	1.42	1	0.002	0.003
							Total	139.730

Column 2 - Severity Rating for Other Miners, which was similarly given a value of 1 if the fire was rated slight (i.e., had little chance of spreading, and would probably self-extinguish when heat source was removed); a value of 3 if the fire was moderate (i.e., had some chance of spreading, and the burning substance was likely to have continued to burn after the heat source was removed); and 5 if the fire was rated as severe with respect to other miners, (i.e., was very likely to spread to a secondary part of the vehicle or to the mine itself). By weighting fire incidents in this manner, greater emphasis was put upon danger to other miners than to the single operator involved.

Column 3 - Estimated Proportion of Miners Exposed to Danger, which was based upon percentages of men likely to be exposed to danger when the fire took place in a particular part of the mine, and when a particular mining technique was in use. Table 13 summarizes the percentages used in estimating the proportion of men likely to be exposed to potential danger during particular types of incidents. In each case, the particular incident involved was rated according to the type of mining technique and part of the mine actually involved.

TABLE 13

PERCENT OF MEN EXPOSED TO FIRE HAZARD

	Working Area			
Mining Technique	Face	Haulage	Maintenance	Average
Caving	5%	45%	10%	20%
Room and Pillar	55%	65%	15%	45%
Cut and Fill	25%	80%	20%	42%

Column 4, Weighted Severity for Other Miners, in which the severity rating for other miners (Column 2) was multiplied by the proportion of miners estimated to have been exposed to danger (Column 3).

Column 5 - Overall Severity for Operator and Other Miners, which was computed by adding the severity rating for the operator (Column 1) to the weighted severity for other miners (Column 4).

Column 6 - Estimated Total Incidents of this Type in Mine Over Five Years, which was simply the estimated number of incidents of this type per year (from Tables 4 through 7) times five years.

Column 7 - Percentage of Total Incidents Represented, a weighting factor obtained by dividing the number of total incidents over a five-year period (Column 6) by the total number of incidents reported in Column 6, which for load-haul-dumps (Table 9) was 100 incidents; and finally,

Column 8 - Weighted Overall Fire Hazard Rating for this Incident, which weighted (multiplied) the overall severity for operator and other miners (Column 5) by the percentage of total incidents represented (Column 7). The total of this last column yielded the total weighted overall fire hazard rating for the type of vehicle, used in Table 8, Column 1.

Examining the above fire severity ratings somewhat further, it is instructive to note in Figures 9 and 10 that a majority of the 55 individual fire incidents investigated in this study presented only slight danger to the vehicle operator himself, but a moderate danger to the other miners working when the incident occurred. In terms of proportions of the mine workers exposed to dangers at any degree of severity whatever, Figure 10 indicates that most ifre incidents (50%) exposed only from 41% to 60% of the miners to danger, however slight. The severe fire is, on this analysis, a very infrequent event insofar as mobile underground equipment is concerned.

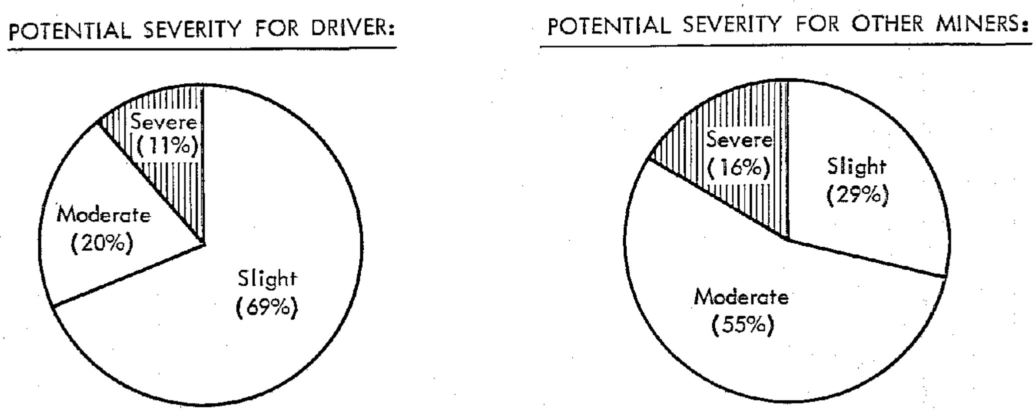


Figure 9 - Comparative Potential Severities of 55 Investigated Fire Incidents

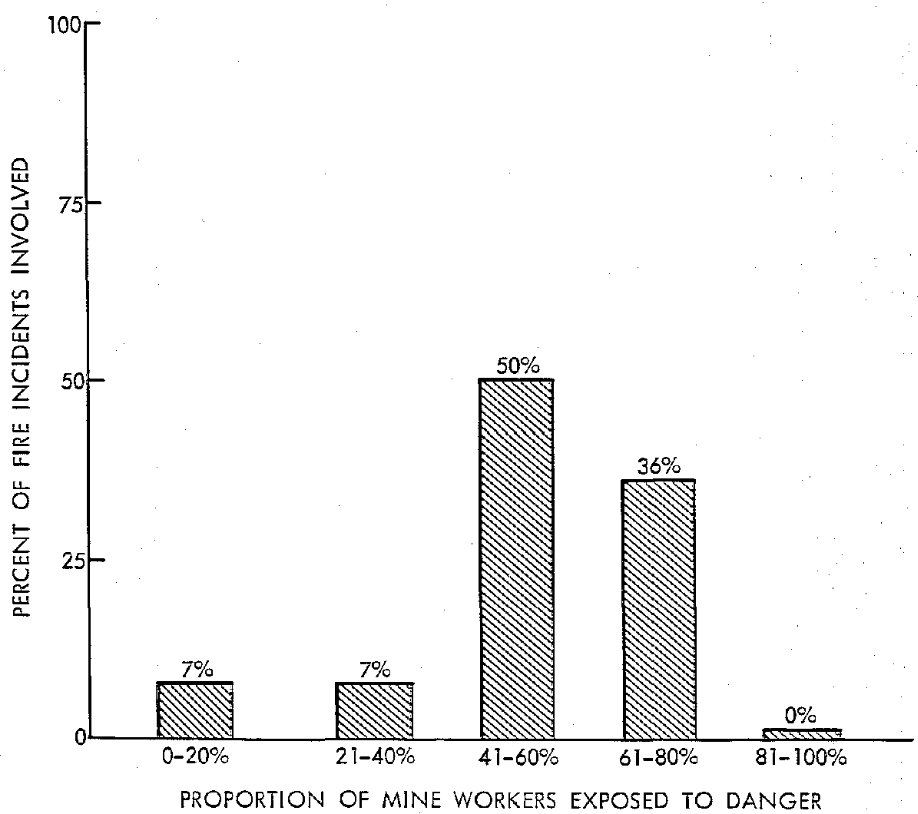


Figure 10 - Proportions of Mine Workers Exposed to Potential Danger During 55 Investigated Fires (All Equipment Types)

Turning now to the final major hazardousness measure used in Table 2, Table 14 summarizes the subjective hazardousness ratings mine officials gave to each of the four types of equipment most frequently associated with actual fires, in addition to those they gave other types of underground equipment. It is relevant to note that, without knowing the results of the present analyses of the hazardousness of the different types of vehicles, mining officials rated the front-end loader and the haulage truck--two of the four types identified above--as being first and second, respectively, in "hazardousness." The load-haul-dump was then rated fourth overall, and locomotive/cars were rated seventh overall, compared with other types of equipment. To preserve continuity in the anlysis, only the relative ranking positions of the four types of vehicles currently of interest were used in Table 2. Following this approach, the relative ranks received by these four types of equipment were front-end loader (1), haulage truck (2), load-haul-dump (3), and locomotive/cars (4).

Table 14
Mine Managers' Ratings of Fire Hazardousness
for 10 Different Types of Mobile Underground Equipment
(N = 13 Managers)

Equipment Type	Average "Hazardousness" Rating by Operators	Overall Rank (1 = Most Hazardous)	Relative Rank of Four Equipment Types of Interest
Front-End Loader	6.12	1	1
Haulage Truck	6.20	2	2
Bulldozer	7.44	3	
Load-Haul-Dump	7.92	4	3
Service/Mtnce. Veh.	8.24	5	
Personnel Vehicle	8.92	6	
Locomotive/Cars	9.45	7	4
Grader	9.60	8	
Powder Loader	9.92	9	
Drill	9.96	10	

In Figure 11, these results are graphed so as to illustrate the average ratings actually given the four types of vehicles of interest. Here the rating scale is reversed, to facilitate comparison with earlier graphs; actual average ratings were subtracted from a constant of 10, so that lower figures indicate lower hazardousness ratings.

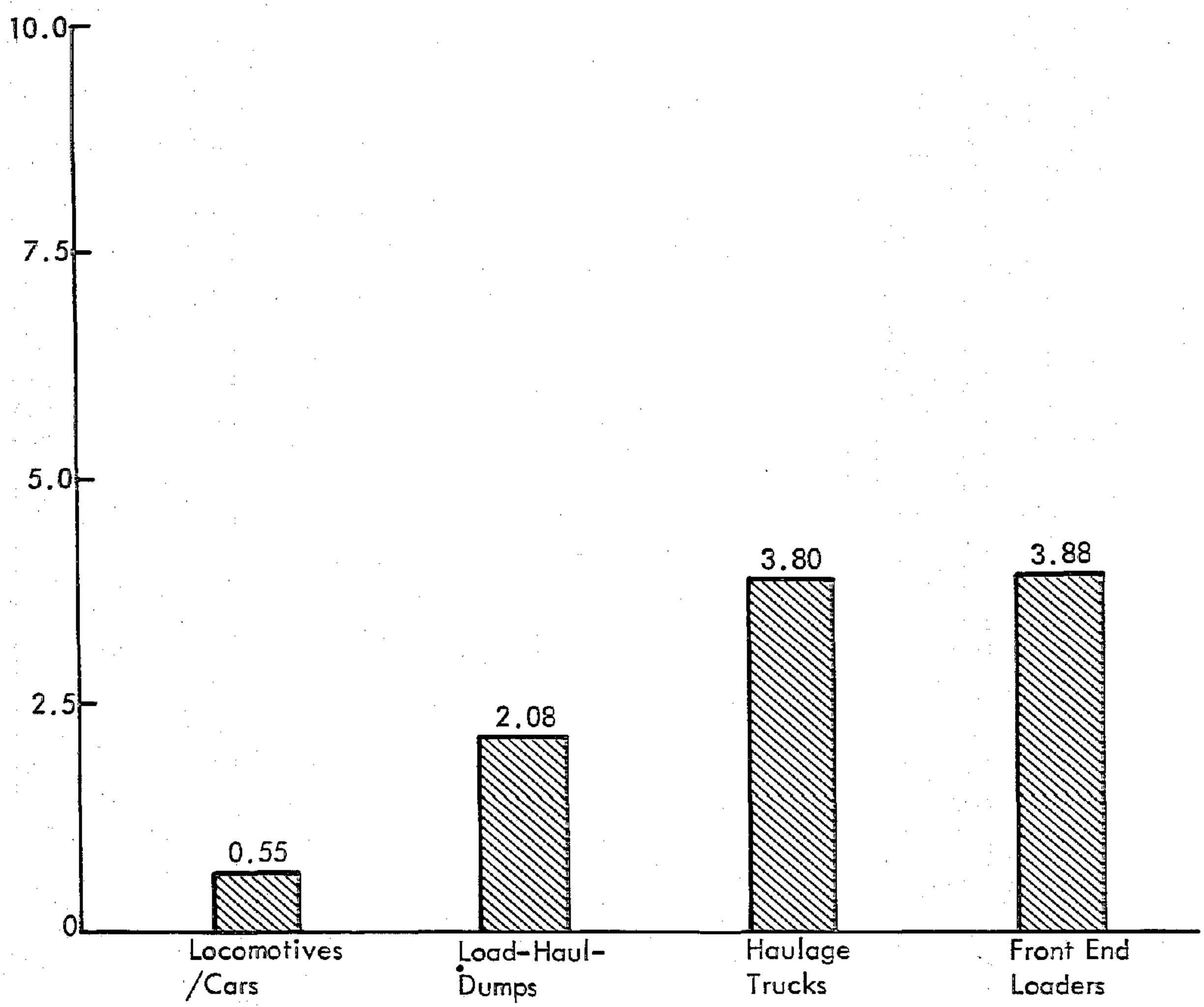


Figure 11 - Average Subjective Ratings of Vehicle Hazardousness by Mine Managers (10 = Most Hazardous)

4.2 Fire Incident Characteristics Analysis

As was indicated earlier in Section 4.0, (2), Analysis of Data, load-haul-dump and front-end loader fires tended to involve different parts of the vehicles, with a certain degree of overlap in the particular parts of the vehicles involved. A fuller analysis of the parts of the vehicles, heat sources, and substances burning in LHD and FEL fires are provided in Tables 15 and 16, respectively.

The last column in both tables, the "calculated hazard rating" for the part of the vehicle involved, was computed as follows: for each incident, the overall fire hazard rating for the incident was taken from Table 9 (for LHD's) and from Table 10 (for FEL's), in Column 8 of each table. The particular part of the vehicle involved--e.g., hydraulic hose on left side of engine at output from hydraulic pump--was noted for that particular incident. These hazard ratings were then summed over all incidents in which part of the vehicle was involved.

Following this procedure, it is seen from Table 15, for example, that the most hazardous particular part of the load-haul-dump (LHD) was determined to be hydraulic hoses located at articulation points on the vehicle (calculated hazard rating over all incidents = 119).

In Table 16, the most hazardous part of the front-end loader (FEL) is seen to have been the compressor hose in the engine compartment, with a hazard rating of 170.

Although the actual figures are not provided in this report, it should be noted that elimination of fire incidents rated minor in severity has no substantial effect upon these findings. Under this restriction, for example, the most hazardous parts of the LHD include those mentioned in Table 15 except for wiring and battery cable parts, whose hazard ratings go from very low (e.g., 1 or 3) to zero.

TABLE 15

ANALYSIS OF CHARACTERISTICS OF LOAD-HAUL-DUMP FIRES

Vehicle Part Involved	Heat Source	Substances Burning	Calculated Hazard Rating
Hydraulic Hose			
On left side of engine at output from hydraulic pump	Friction resulting from high velocity in plugged hose	Hydraulic fluid	23
At articulation point	Various	Hydraulic fluid	119
On boom	Sparks from ground fall	Hydraulic fluid	47
On boom	Sparks from crash	Hydraulic fluid	5
Engine Compartment			
Sump	Engine	Rags in sump	47
Area above differential	Friction	Grease and oil	9
Wiring			
Panel	Short	Insulation	1
In articulation point	Short	Insulation	1
Battery Cable			
Near battery under seat	Short	Insulation	1
Inside battery case	Short	Insulation	1

TABLE 16

ANALYSIS OF CHARACTERISTICS OF FRONT END LOADER FIRES

Vehicle Part Involved	Heat Source	Substances Burning	Calculated Hazard Rating
Compressor Hose In engine compartment	Friction resulting from high velocity in plugged hose.	Carbon	170
Driver Compartment	Battery cable short	Hydraulic fluid	20
Engine Compartment	Exhaust manifold	Hydraulic fluid	20
Hydraulic Hose	Exhaust manifold	Hydraulic fluid	20
Battery Cable Below Seat	Battery cable short	Hydraulic fluid and fuel	19

4.3 Vehicle Operating Environments Analysis

In this section, fuller details are provided regarding the environmental characteristics of the mines visited during the study. To the extent the mines visited are considered representative of operating environments for the types of vehicles under consideration, these characteristics reflect the environmental conditions under which any automatic fire control system (AFCS) designed, will need to be able to function.

Figures 12 through 15 show, in statistical ogive (i.e., cumulative frequency) form, the relative frequencies with which particular temperatures, humidities, lowest tunnel clearances and average tunnel clearances, respectively, that an AFCS will encounter. In addition to giving the absolute and cumulative frequencies of each condition, these figures also give the mean (average), median (midpoint figure), and mode (most frequent figure) for each range of values.

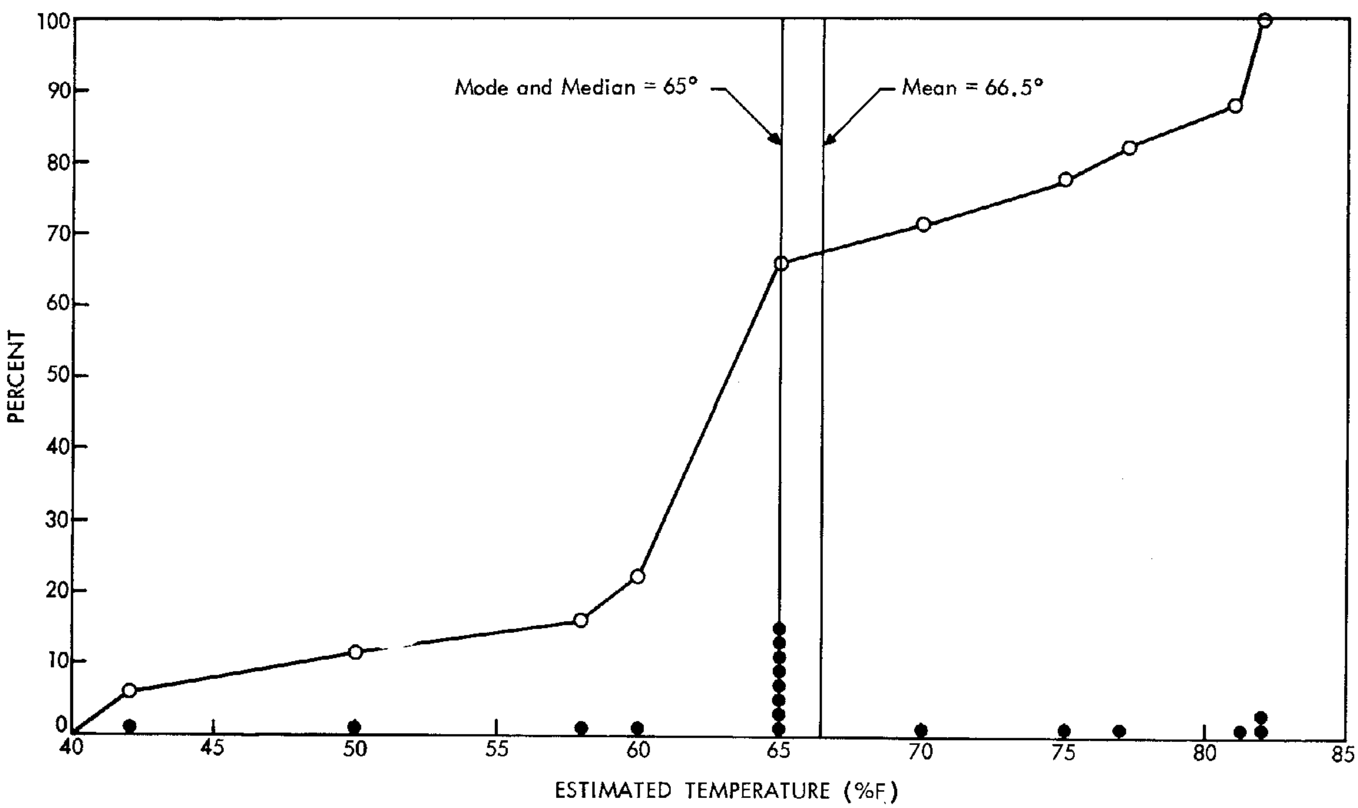


Figure 12 - Estimated Mine Temperature in Degrees: Cumulative Percent of Mines (N = 18)

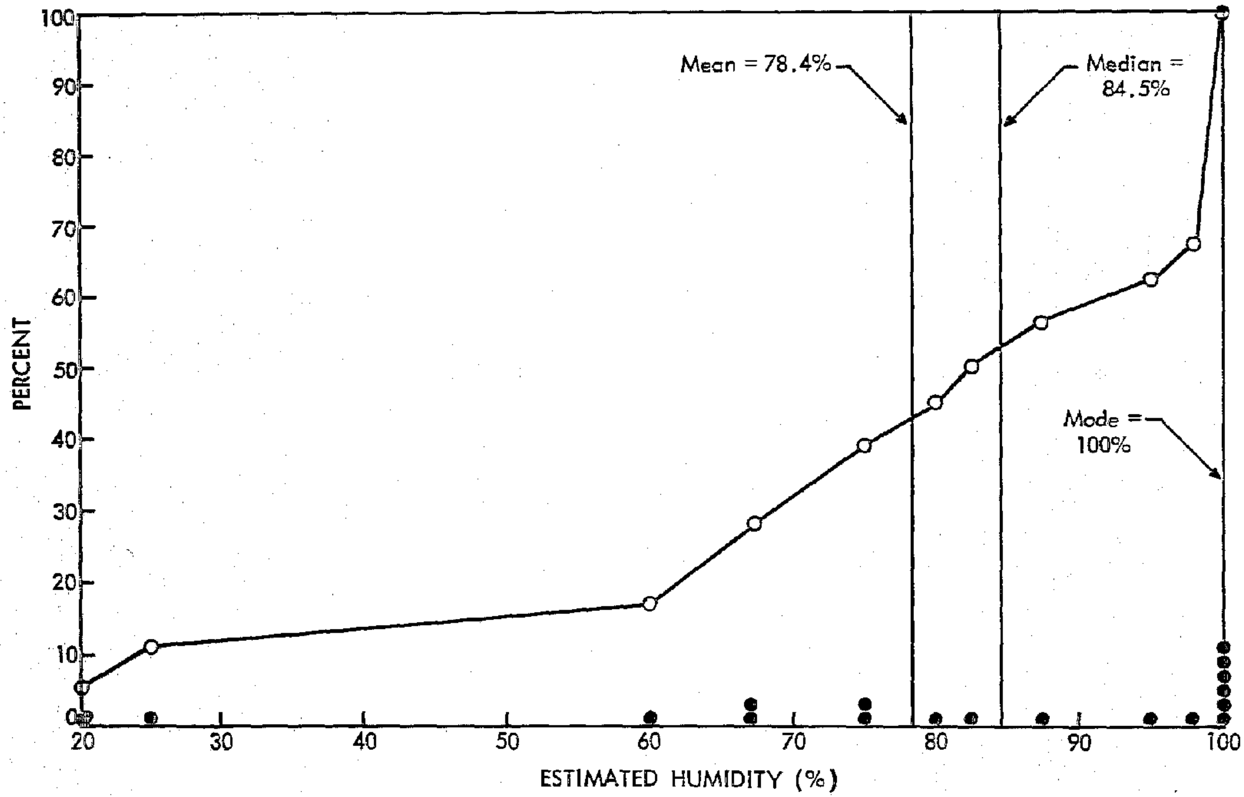


Figure 13 - Mine Humidity in Percent: Cumulative Percent of Mines (N = 18)

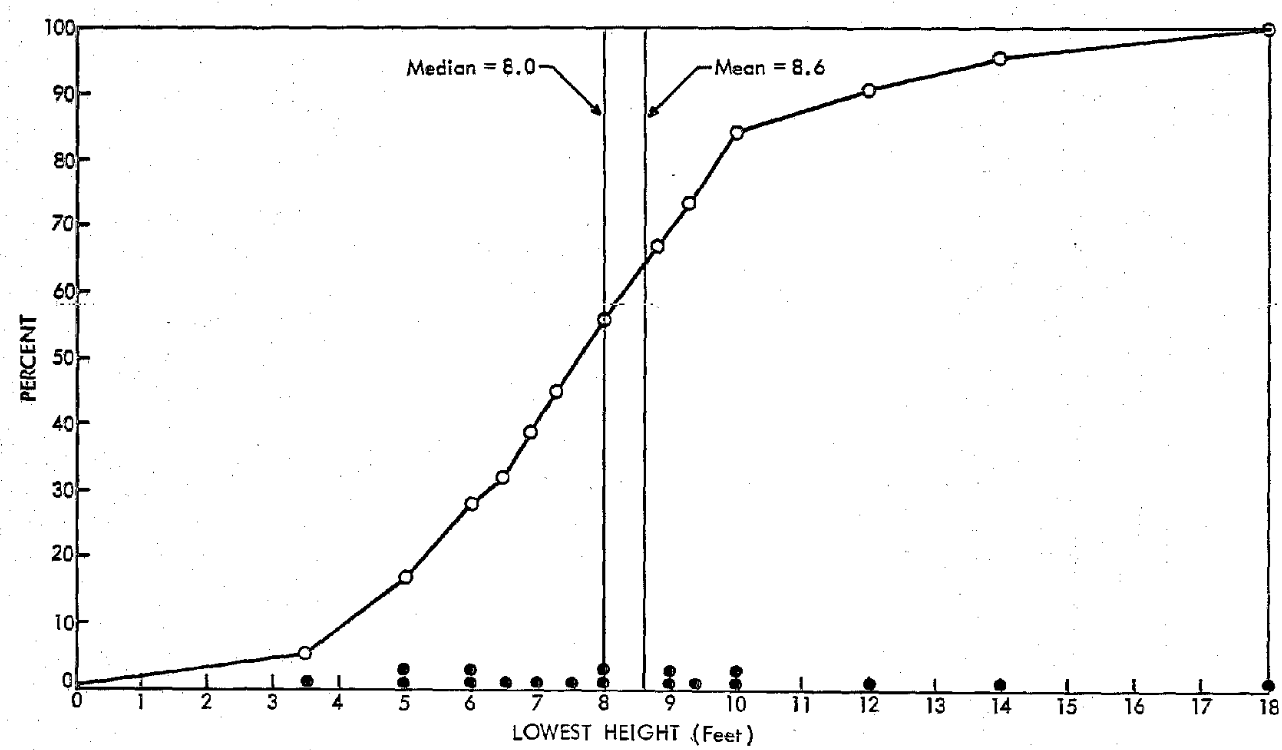


Figure 14 - Lowest Tunnel Clearance Height in Feet: Cumulative Percent of Mines (N = 18)

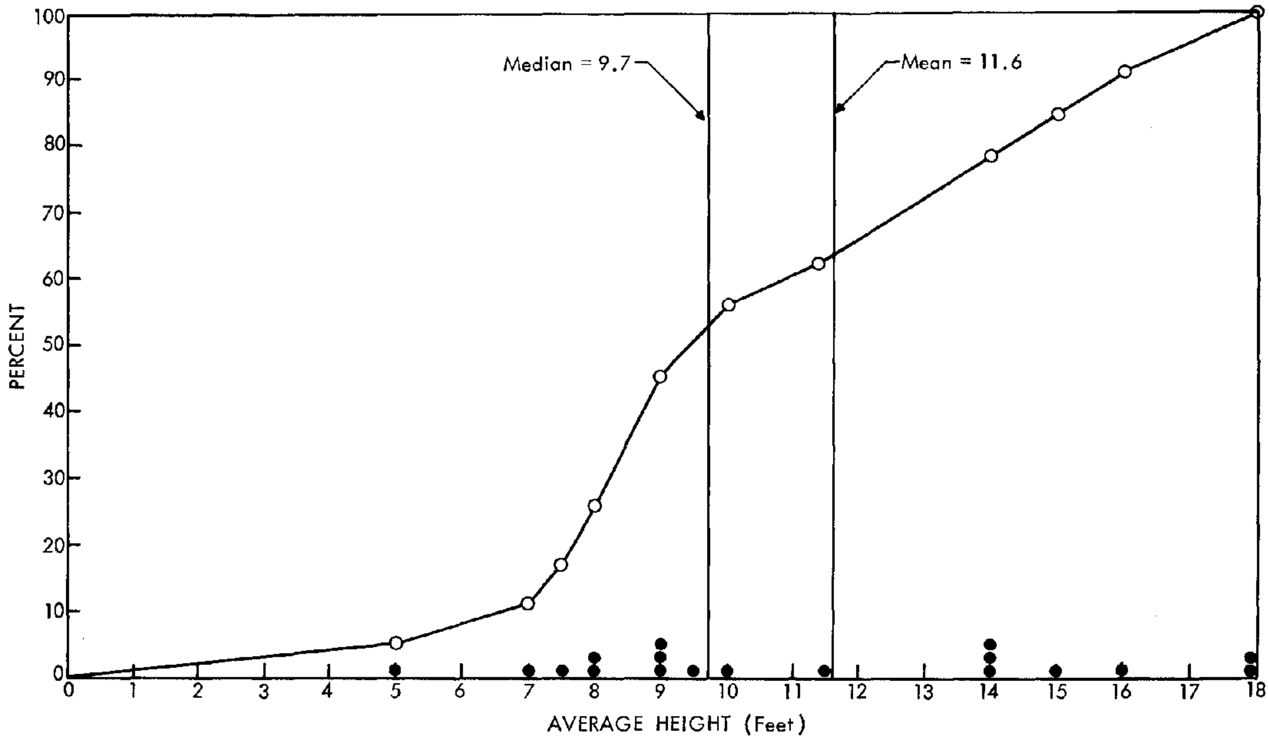


Figure 15 - Average Tunnel Clearance Height in Feet: Cumulative Percent of Mines (N = 18)

4.4 Vehicle Condition and Maintenance Procedures Analysis

Tables 17 through 19 summarize, respectively, the vibration and shock levels observed to be encountered by LHD's and FEL's; the types of corrosive chemicals and chemical byproducts observed collecting on these types of vehicles; and the kinds of cleaning compounds and substances found to be used on these vehicles. In each of these three tables, the numbers indicate the number of mines in which the particular type of condition or circumstance was encountered or observed. Often, the same mine might yield several observations or instances of different types.

COMPARATIVE ANALYSIS OF VEHICLE OPERATING CONDITIONS OBSERVED FOR LOAD-HAUL-DUMPS AND FRONT END LOADERS

Table 17

Vehicle Operating Condition Observed: Category	Type	Load-Haul-Dump	Front End Loader	Both
Moving Vibration Levels	Paved Road	1	0	1
	Gravel Road	4	2	6
	Potholes	4	2	6
Stationary Vibration Levels	Little or None	6	1	7
	Medium	4	2	6
	Severe	0	0	0
Shocks Vehicle Encountered	Springs Bottoming	7	3	10
	Lurching	8	3	11
	Loud Impact Sounds	6	1	7

Note: Multiple conditions possible.

TABLE 18

CORROSIVE CHEMICALS AND BYPRODUCTS OBSERVED COLLECTING ON VEHICLES (instances)

Corrosive Chemicals and Byproducts Observed Collecting on Vehicle	Load-Haul-Dump	Front End Loader	Both
Sulfides	1	1	2
Sulfates	1	0	1
Sulfuric Acid	3	0	3
Diesel Exhaust	1	1	2
Ammonium Nitrate	1	0	1
Battery Acid	1	0	1

Note: Multiple observations possible within instances.

TABLE 19

CLEANING COMPOUNDS AND SUBSTANCES USED DURING VEHICLE MAINTENANCE (INSTANCES OF REPORTED USAGE)

Cleaning Compounds and Substances Used on Vehicle	Load-Haul-Dump	Front End Loader	Both
Pressurized Water	4	2	6
High-Pressure Steam	6	1	7
Caustic Detergent	1	1	2
Esso Away (Petroleum)	1	1	2
Westlube (Alkaline)	2		2
FO 2-21 Solvent	2		2
Magnasol Cleaner	1		1

Note: Multiple Applications Possible.

4.5 System Marketing Factors Analysis

This section provides details concerning performance, cost, and maintenance factors likely to affect purchases of any AFCS developed for mobile underground mining equipment.

Section 4.0 (5) summarizes the relative importance given various AFCS characteristics in decisions to purchase or not to purchase such fire control systems for underground vehicles. In Tables 20 and 21, the actual average ratings underlying these rankings are summarized, together with the standard deviations (S.D.) for these average ratings. Lower S.D.'s indicate less disagreement (i.e., more unanimity) regarding the importance ratings for an individual characteristic of AFCS'.

Here it is seen that, while control system reliability ranked first in importance on the average (Table 20), there was less general agreement concerning the importance of this characteristic (S.D. = 2.28) than there was concerning the importance of ease of maintenance, which ranked second (S.D. = 1.28). Regarding the different decision factors, however (Table 21), the factor ranking first (replacement/reorder time for vehicle) also showed high agreement (S.D. = 0.65), compared with the ratings given most other decision factors.

Finally, Figures 16 through 23 provide illustrations of the absolute and cumulative frequencies with which mine officials cited particular purchase prices, maintenance expenses, vehicle life expectancies and system life expectancies as being desirable for any AFCS developed as a result of this study. In each case, two ogives are provided, the first showing the percentage of respondents, e.g., willing to pay a particular percentage or more of the vehicle purchase price for an AFCS (Figure 16), and the second showing the percentages of total vehicles "covered" or represented by these ratings obtained (e.g., Figure 17). As before, the mean, median, and modal responses are given for each distribution on the ogive.

TABLE 20

RANKING OF VARIOUS AFCS CHARACTERISTICS

AFCS Characteristic	Average Rating (1 = Highest)	Standard Deviation	Rank
Control System Reliability	2.62	2.28	1
Ease of Maintenance for Control System	3.35	1.28	2
Frequency of Maintenance for Control System	3.69	2.20	3
Control System Purchase Price	4.58	2.70	4
Maintenance Cost of Control System	4.73	2.36	5
Operator Training Required to Operate Control System	5.73	1.87	6
Location of Control System on Vehicle	5.85	2.21	7
Ease of Installation of Control System	6.73	1.73	8

TABLE 21

RANKINGS OF FACTORS AFFECTING DECISIONS TO INSTALL AFCS

AFCS Installation Decision Factor	Average Factor Rating (1 = Highest)	Standard Deviation	Rank
Replacement/Reorder Time for Vehicle	1.88	0.65	1
Replacement Cost of Vehicle	2.50	0.91	2
Duty Cycle of Vehicle	2.69	1.25	3
Other (lost production, maintenance cost)	3.54	1.85	4
Insurance Rate Reductions	4.38	0.65	5

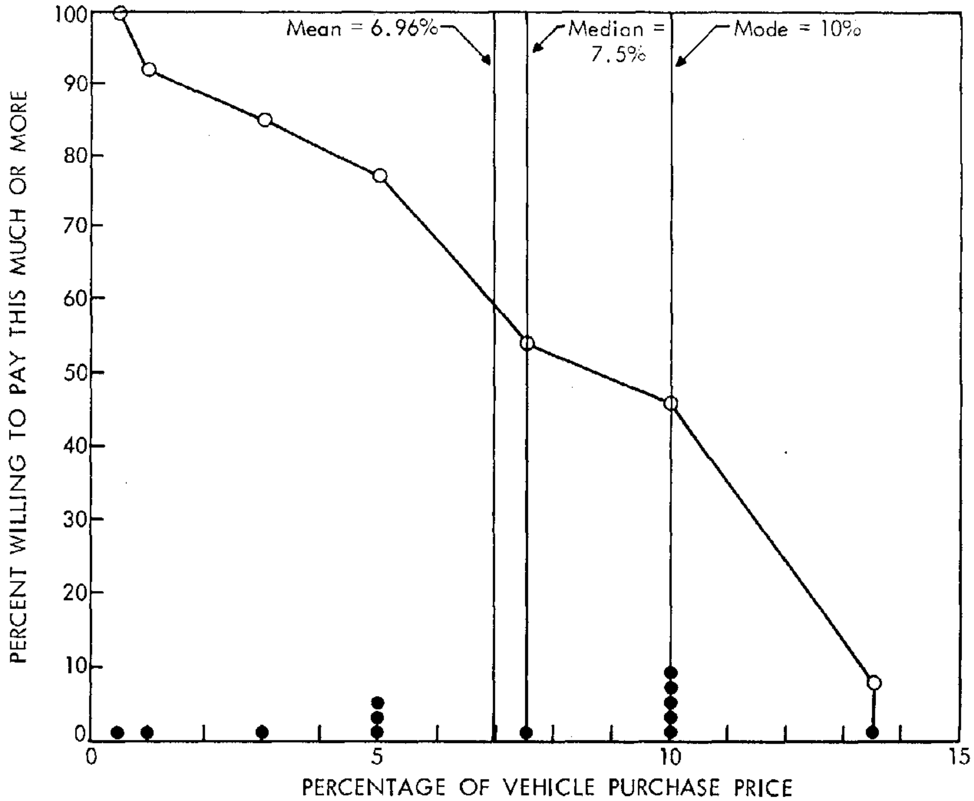


Figure 16 - Percentage of Vehicle Purchase Price Manager is Willing to Pay for AFCS: Cumulative Percentage of Mines (N = 13)

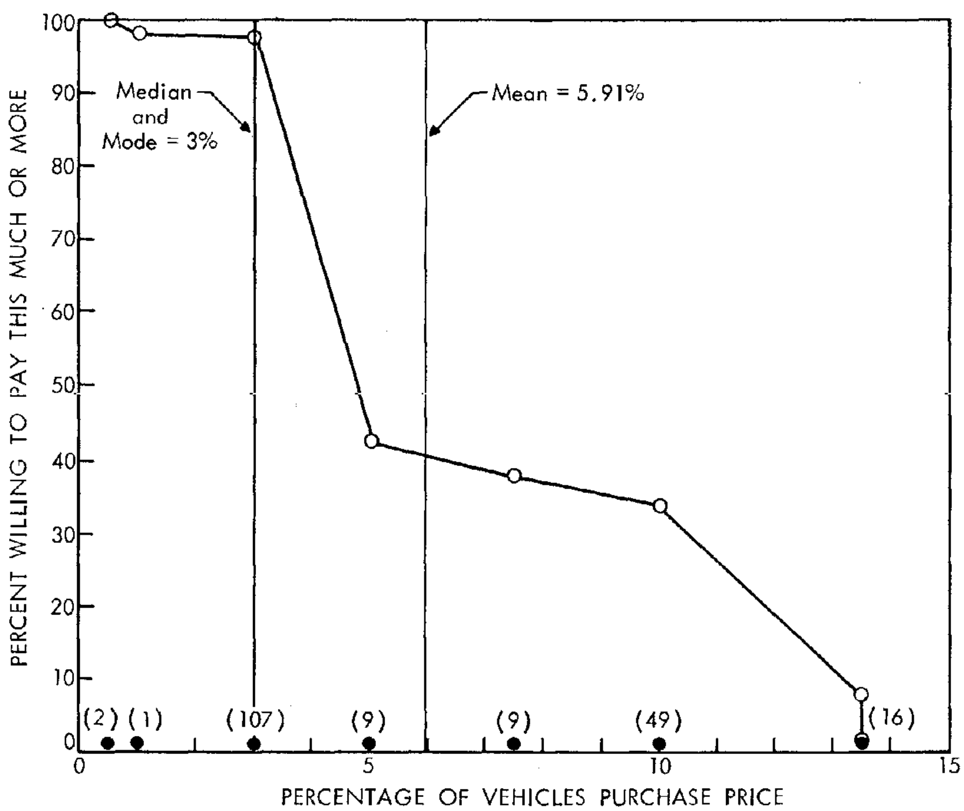


Figure 17 - Percentage of Vehicle Purchase Price Manager is Willing to Pay for AFCS: Cumulative Percentage of Vehicles (N = 193)

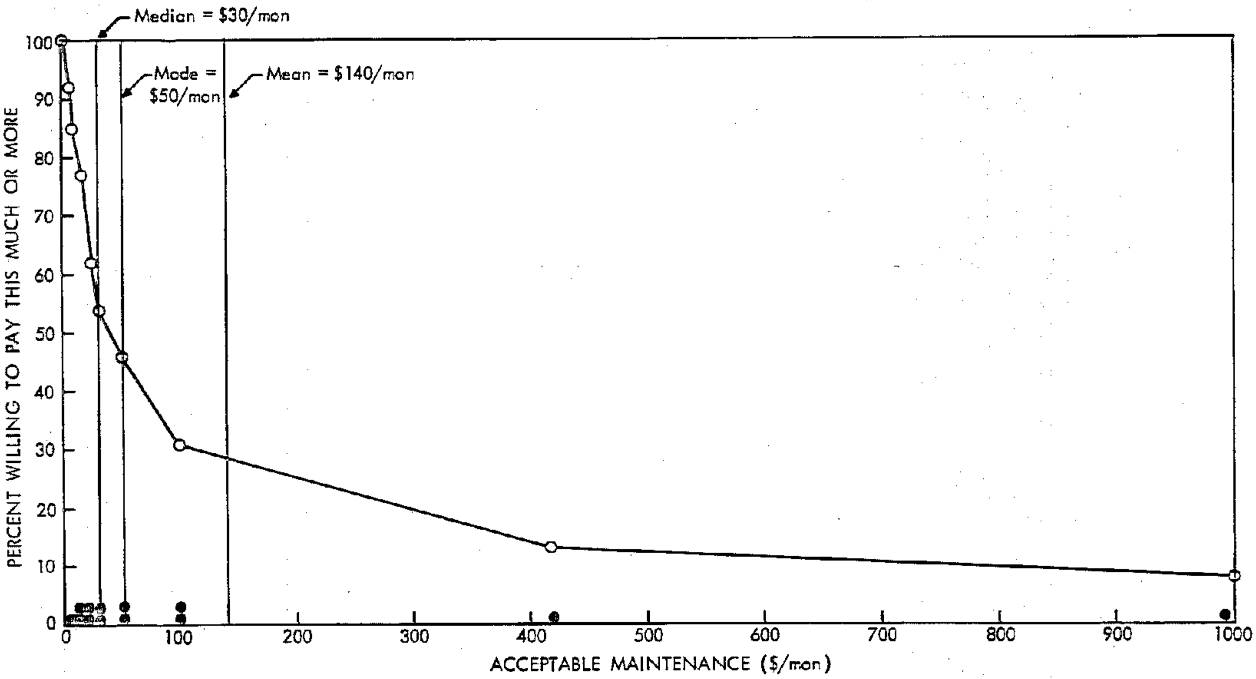


Figure 18 - Acceptable Maintenance Expense for AFCS ($/month):
Cumulative Percent of Mines (N = 13)

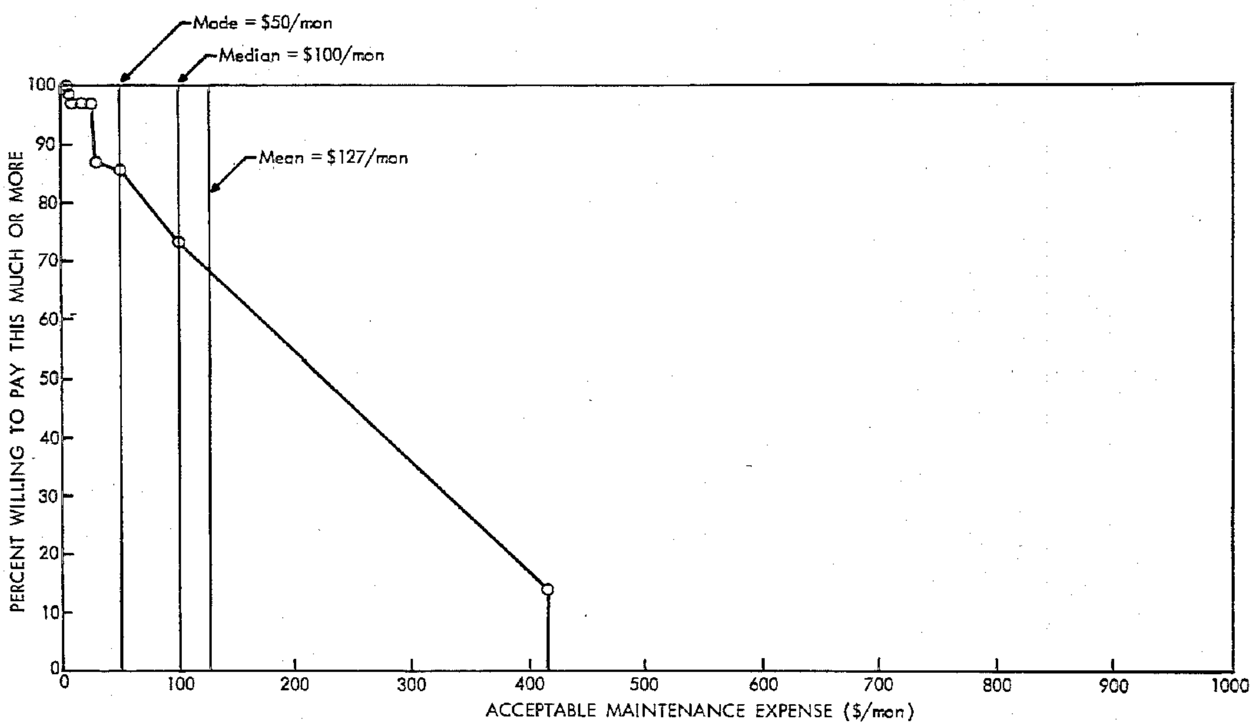


Figure 19 - Acceptable Maintenance Expense for AFCS ($/month):
Cumulative Percent of Vehicles (N = 193)

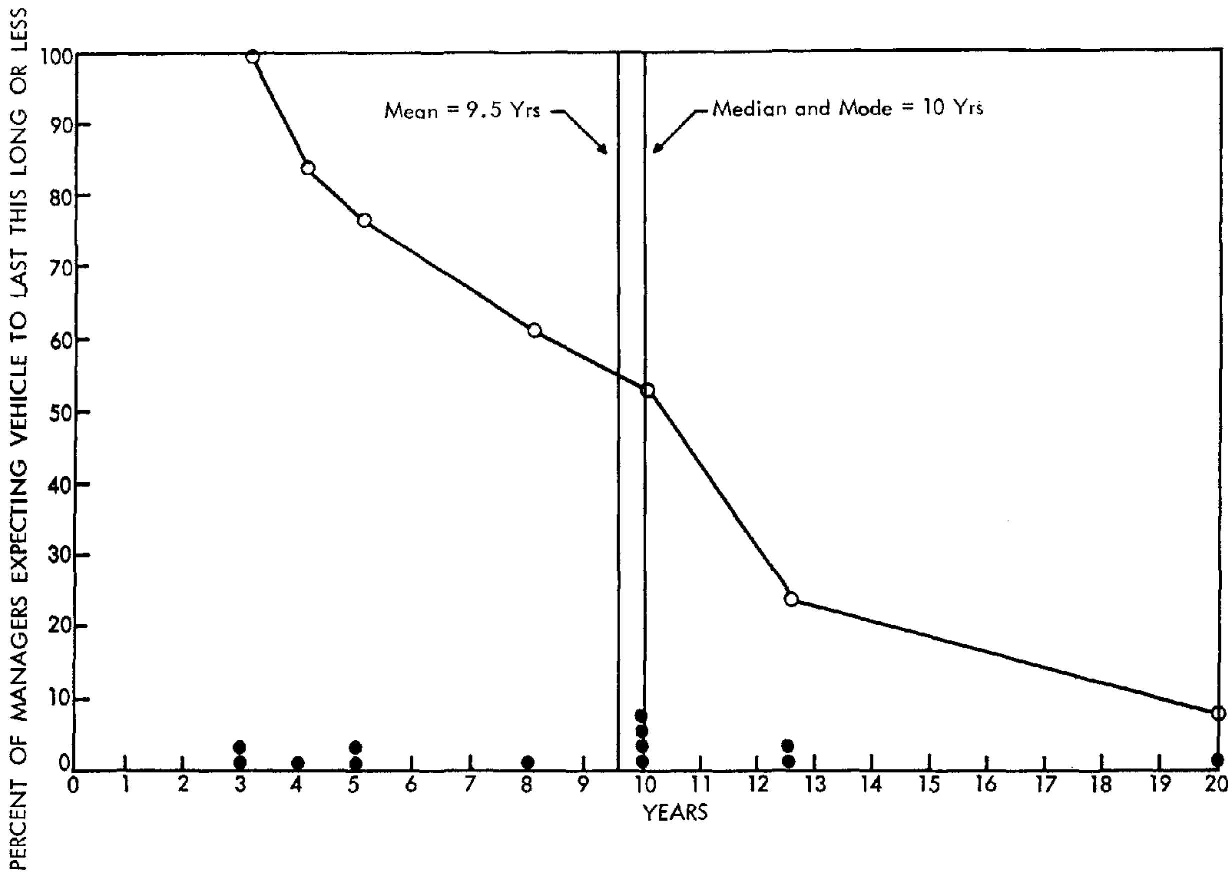


Figure 20 - Years an Underground Vehicle is Expected to Last: Cumulative Percentage of Mines (N = 13)

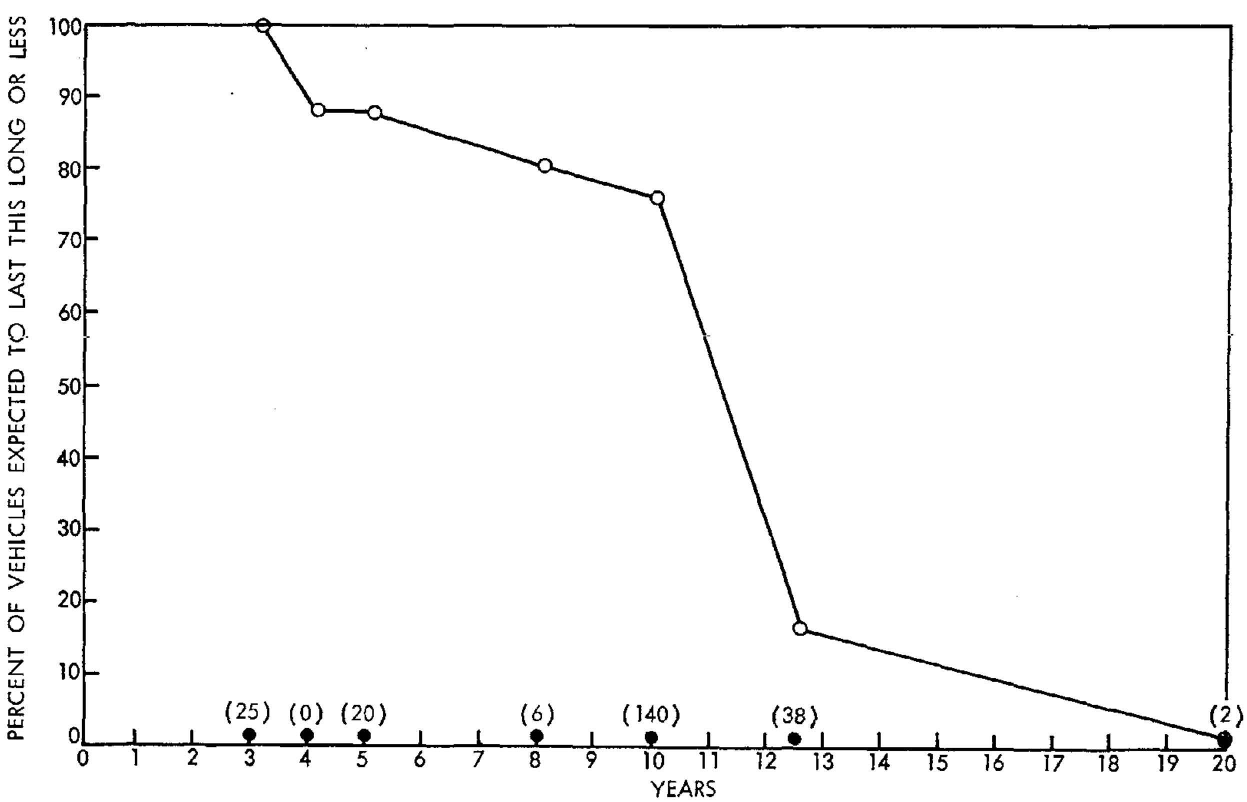


Figure 21 - Years an Underground Vehicle is Expected to Last: Cumulative Percentage of Vehicles (N = 231)

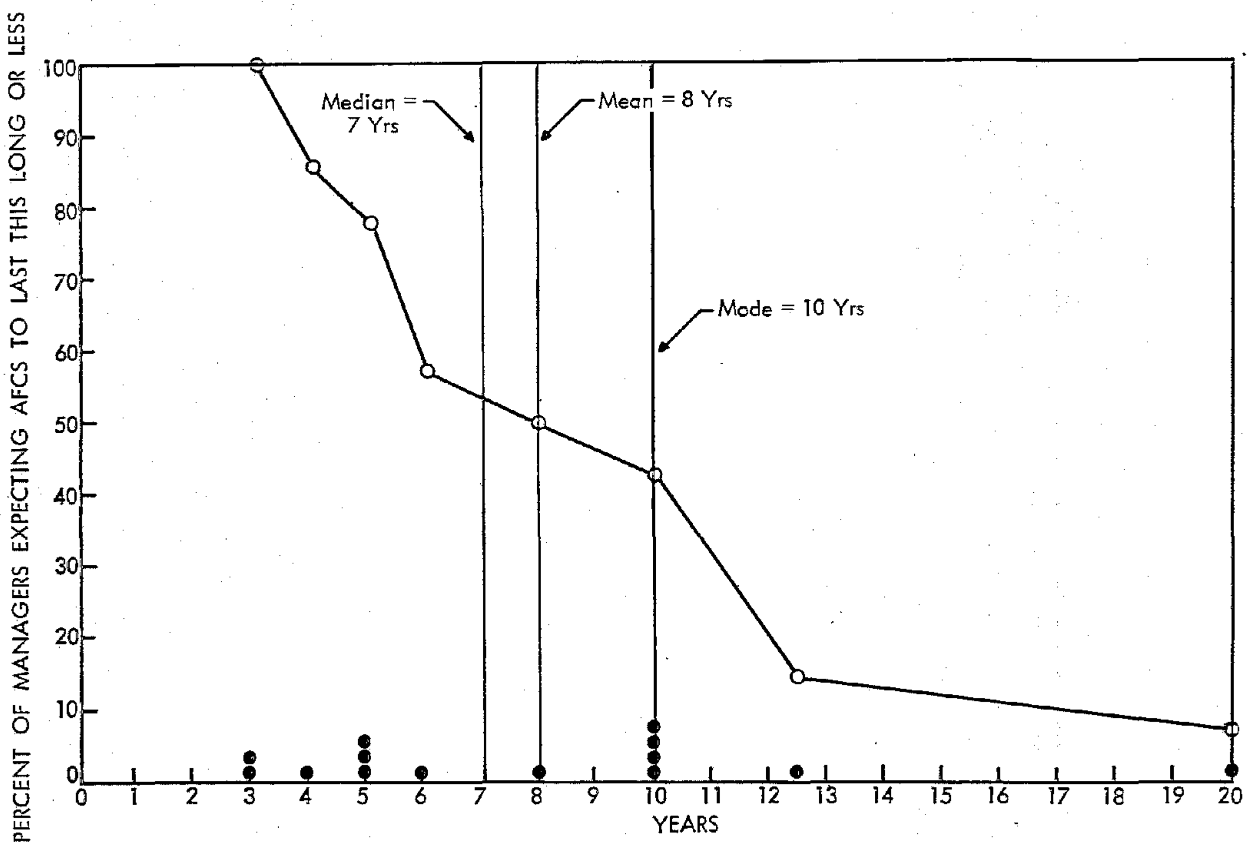


Figure 22 - Years an AFCS Would Be Expected to Last:
Cumulative Percentage of Mines (N = 14)

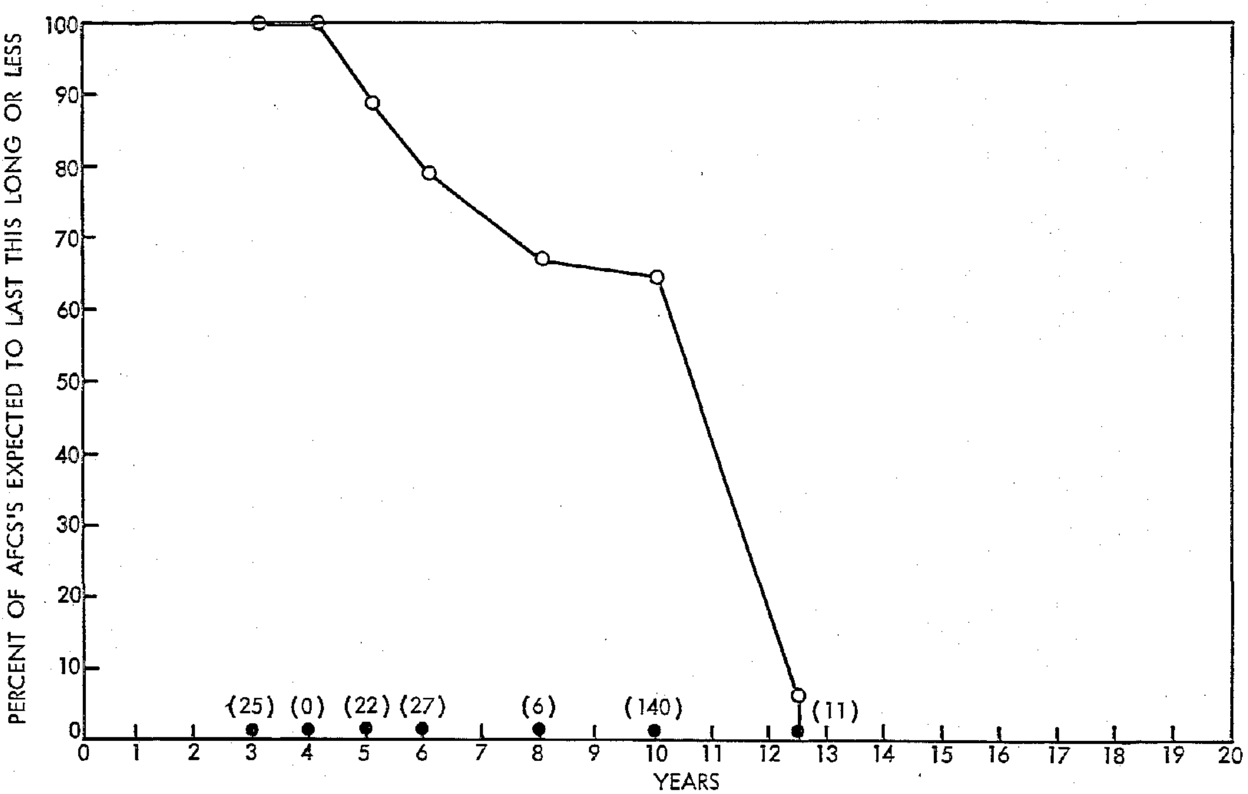


Figure 23 - Years an AFCS Would be Expected to Last:
Cumulative Percentage of Vehicles (N = 231)

5.0 SYSTEM DESIGN CONCEPT

5.1 The Vehicle to be Protected

Although the frequency of occurrence of actual fires, as determined by the mine survey, on LHD equipment was extremely low, the great number of these machines which are in the mines now, their working location relative to escape routes, and the projected annual growth of their use awards them the distinction of being the most likely vehicle to cause a major disaster if a fire were to occur. The following discussion will present further justification for this statement.

5.1.1 Typical Specifications for an LHD:

Steering	Hydraulic cylinders articulate the vehicle. Steering is lost with engine shutdown.
Engine	Air cooled Deutz diesel engines are most common.
Transmission	Two speed automatic torque converter forward and reverse modes.
Drive Train	Four-wheel drive, independent differentials front and rear.
Exhaust Treatment	Water cooled scrubbers, and/or catalytic converters.
Brakes	All four wheels and parking brake on drive shaft. Brakes could be either drum or disc and are actuated by either air or fluid pressure, depending on manufacturer's preference.
Tires	Synthetic rubber compounds.

Operator Location

- Larger Models (2 Cu. Yd. Bucket and Above)

  Operator sits on side of vehicle (either right or left depending on manufacturer's preference) near articulation point and adjacent to torque converter area.

- Smaller Models (Less Than 2 Cu. Yd. Bucket)

  Operator sits in center of vehicle, forward of engine compartment, above torque converter area, and facing forward (toward bucket).

Operator Visibility

- Larger Models

View of surrounding area while moving forward and reverse	Good
Top of engine compartment	Good
Top of torque converter area	Good
Articulation point	Good
Forward differential area and bucket	Good

- Smaller Models

View of surrounding area while moving forward	Good
View of surrounding area while moving reverse	Poor (operator's seat faces forward)
Top of engine compartment	Poor (it is behind driver)
Top of torque converter area	Good (driver sits above this area)

Articulation point	Good
Forward differential area and bucket	Good

5.1.2 <u>Factors Contributing to LHD Fires</u>:

It requires mentioning that the vehicle manufacturers themselves have made a concerted effort to design their vehicles in such a manner that the sources of fuel (hydraulic lines, fuel lines, etc.) have been kept separated as much as possible from those sources of ignition (exhaust manifolds, etc.) which could cause a serious fire. The low-profile, compact nature of the machines has helped this effort considerably. Nonetheless, the basic design has been aimed at achieving a lower overall potential fire hazard.

Regardless of the manufacturers design efforts, and regardless of the fact that extremely few serious LHD fires have been discovered as a result of this study, the LHD still remains a potential fire hazard. The following paragraphs discuss the most obvious examples of conditions which may create a hazardous situation.

- The environment in which the LHD works is highly abusive to the machines. They are most frequently operated in extremely tight quarters, often times being slammed up against the sides of drifts and into muck piles. This not only causes damage to the machine and its components, but also causes sparks and over-stressed situations which could initiate a fire if the appropriate conditions were present.

  In addition to this direct physical abuse, operators frequently over-stress the machines in other ways. Typical examples are: attempting to lift a load which exceeds the capacity of the machine, riding the braking system, operating the vehicle with the parking brake on, shifting transmission from forward to reverse prior to stopping, or any number of other actions which greatly increase the possibility of rupturing hoses and over-heating particular components of the machine. Obviously, a combination of a spraying fuel (hydraulic or diesel) and a high temperature source (hot manifolds, or housings) could lead to a fire condition.

- In many mines, the emphasis on production is so great that the LHD (a primary production vehicle) does not receive the preventative maintenance that it requires. Hydraulic hoses are allowed to wear to the point of rupture before they are replaced. Hydraulic and other fluids are allowed to leak from, and cover all areas of the machine. Rags, paper, muck, and other debris is allowed to collect in every conceivable location of the machine. And, rarely is anything but the engine cleaned on any regular basis. All of these situations contribute to potential fire hazards.

- The most frequent fires that have been discovered on LHD's are electrical shorts in the dashboard of the machines. Although this is not a serious fire in any respect, the result of such a fire may become hazardous at a later date. Because of the high emphasis on production, when a fire of this scale occurs the electrical short is usually just eliminated from the circuit altogether. Eventually, the only circuits that are left operative are the lights and whatever else is absolutely necessary to keep the machine operating. Gages, warning lights, and other such devices may be disconnected leaving the operator unaware of the emergency conditions for which they were intended. Again, a high temperature or over stressed condition may result, posing a potential fire hazard.

5.2 General Design Criteria for an Automatic Fire Control System

- The most likely fire that will occur on an LHD is one involving either combustible liquids, or electrical shorts (B and C Class fires, respectively). However, because of the presence of hydraulic hose, wiring insulation, and collected debris (all of which are Class A fire materials) the agent chosen for this application must be effective against all three classes of fires.

- The agent must be applied to those areas of the machine which have both a potential source of ignition, and a fuel to be ignited. However, because of the limited space available on the machine for the installation of an AFCS, system protection should be limited to those areas which cannot be protected with a hand portable extinguisher alone. This practice will also help eliminate the discharge of the AFCS for minor fires, a situation which would be a nuisance to the mine operators.

- The detection portion of the automatic system must react to a major fire condition within a reasonable time (between 10 and 15 seconds). However, reaction time is not the critical issue. Durability, reliability, maintainability, and infrequency of false alarms are the most important factors to be considered when choosing the type of sensor to be used.

- The agent container should be able to withstand the rugged environment with little maintenance.

- The agent container should be easily serviced (refilled) in the mine, and without the aid of specialized equipment.

- The design of the agent container should allow for the periodic inspection of the extinguishing agent.

- The agent release mechanism must operate reliably in a high shock and vibration environment.

- The agent distribution system (piping and nozzles) must be able to withstand a high shock and vibration environment.

- A provision must be made to allow either for sealing, or for the periodic cleaning (or purging) of the agent distribution system to insure the free passage of agent.

- In addition to automatic actuation, at least two manual actuation points must be provided (one in the operator's compartment and one in the opposite side of the vehicle).

- Each mode of actuation must be able to actuate the AFCS independently of the other two.

- The control unit must have a warning light and an audible alarm (100 db minimum sound level) to insure operator notification of a fire condition.

- The control unit must have a continuous test circuit to be used to monitor the integrity of the detection devices.

- The control unit must have a malfunction warning light which receives its input from the continuous detection test circuit just described. The purpose of this warning light is to notify the operator of any problems within the detection circuit.

- The control unit must have an alarm test switch. The presence of such a switch will enable either operating or maintenance personnel to simulate both fire and malfunction conditions, thus energizing the display lights and audible alarm to insure that they are operative.

- The control unit should have a test switch which will allow for the periodic operation of the automatic actuation device. The switch should be located where only authorized maintenance personnel can operate it (to prevent malicious tampering).

- Either automatic and/or manual actuation of the AFCS should automatically shut down the engine and apply the vehicle's braking system (wheel and parking brakes). The intent of such an action is:

  (1) To shut down all hydraulic, lubricating and diesel oil pumps, thus eliminating a possible source of whatever may be fueling the fire.

  (2) To immediately bring the vehicle to a stop and keep it there in the event that the operator is either unable, or unwilling to do so.

- The AFCS will require maintenance as follows:

Frequency	Maintenance Procedure
Daily (Done by Operator)	• Visually check malfunction warning light and pressure gages (whichever is applicable)
Monthly (Done by Maintenance Department	• Visually check agent nozzles for clogging. • Operate system test switch to insure integrity of warning devices. • Check mounting hardware for tightness.
Semi-Annually (6 months) (Done by Maintenance Department)	• Visually check agent and actuation distribution lines for damage or wear. • Purge distribution system to clear of any debris (if system is unsealed)

Semi-Annually (6 months) continued	• Inspect agent (if possible). • Inspect agent container for damage. • Inspect pressure levels within all pressure vessels (either by weight or by gage). • Inspect agent release mechanism(s). • Visually inspect all actuation mechanism(s). • Inspect sensors. • Repeat all daily and monthly maintenance procedures.
Yearly (Done by Maintenance Department)	• Energize the Automatic Actuation Device (via control unit test swtich) to insure its operation. Take required precautions to avoid agent discharge.
Every Two Years (Done by Maintenance Department)	• Inspect agent tank, all mounting brackets, and all mounting hardware for rust and/or damage. Paint, repair, and/or replace as required.

5.3 Existing Fire Control Systems

- Systems Encountered During Mine Visits

  Only two of the twenty mines that were visited had vehicles on which fire control systems were installed. Since both of these systems were manually operated, complete information concerning them is presented in Appendix C, rather than in this portion of the report. In the interest of confidentiality, the systems will simply be referred to as System 1 and System 2.

- Commercially Available Systems

  There are four major United States based manufacturers of Fire Control Systems for the mobile mining equipment application. Their names and system capabilities are listed in tabular form on Table 22.

TABLE 22

Commercially Available
Mobile Mining Vehicle
Fire Control Systems

Manufacturer: Name	The Ansul Company	Walter Kidde & C., Inc.	Safety First Products Corp.	Graviner Inc.
Location	Marinette, Wisc.	Belville, N.J.	Cornwell Heights, P. A.	Berkeley Heights, N.J.
System Information:				
Type of Agent	ABC, Dry Chemical	ABC, Dry Chemical	ABC, Dry Chemical	1211-Halon gas (BC rating)
Agent Container Size(s), (nominal weights)	10lb, 20lb, & 30lb.	20 lb.	20 lb.	6lb, & 12lb.
Stored pressure, or Cartridge Type Unit	Cartridge	Cartridge	Stored Pressure	Stored Pressure
Method of Actuation	Nitrogen Cartridge	CO_2 Cartridge	CO_2 Cartridge	Electric Switch
Means of Agent Pressurization	CO_2 Cartridge	CO_2 Cartridge	Stored Nitrogen Pressure	Stored Nitrogen Pressure
Means of Conveying Agent from Tank to Nozzles	Hydraulic Hose (1/2" & 3/4")	Hydraulic Hose (1/2" & 3/4")	Pipe or Hydraulic Hose	Rigid Pipe (3/4" ID)
Type of Nozzles (Local Application, or Total Flood)	Both	Local Application	Total Flood	Total Flood
Fire Extinguishing Capabilities ($ft.^2$, & $ft.^3$)	10lb- 25 ft^2, 350 ft^3 20lb- 50 ft^2, 700 ft^3 30lb- 50 ft^2, 1000 ft^3	No Specific Ratings	600 $ft.^3$	6lb- 120 ft^3 12lb- 240 ft^3
System Tested & Approved for Vehicle Application by	Factory Mutual Laboratories	MESA Approved	* see note	* see note
Automatic Features (and costs)	none	Point Source, Thermal Sensors -$ 48.ea. (95% of sales are Manual)	* see note	Linear Thermal- $ 24./ft. Control Box (D.C.) $ 300.
Cost Information:				
List Price for a Standard System (excluding detection)	10lb- $ 218. 20lb- $ 250. 30lb- $ 250.	$270.	* see note	6lb- $ 206. 12lb- $ 252.
Items Included in a Standard System	Agent Tank & Bracket 4-Nozzles & Brackets 1-Actuator & Bracket 1-Expellant gas cartridge 1-Release Mechanism 1-Agent Distribution Tee 1-Pressure Relief Valve Appropriate Quantity of Agent.	Agent Tank & Bracket CO_2 Expellant Gas Cartridge ($2\frac{1}{2}$ lb) 1-Actuator Mechanism 4-Nozzles Gas Cartridge Bracket	* see note	Agent Tank & Bracket 1-Actuator 1-Connector Hose (15") 4-Nozzles (6 lb unit) 8-Nozzles (12 lb unit)

* Information not available

There are also many distributors, and several small speciality houses which put together systems comprised of the various major manufacturers' components. However, because of their great number, and because of the varying degrees of complexity of systems which they offer, they will not be listed in this report. Further information pertaining to these suppliers can be obtained from the major manufacturers directly.

5.4 Evaluation of Specific AFCS Characteristics

5.4.1 Hazards Considered for Protection

The locations on the vehicle which are being considered as hazards have been split into two categories, primary hazards and secondary hazards. Their definitions are as follows:

- Primary Hazards

  Any location on a vehicle which possesses both the fuel and sources of ignition required to initiate a fire is considered a primary hazard. The source of ignition could be either extremely high surface temperatures or severe electrical arcing. The fuels could be either combustible fluids or combustible solids.

- Secondary Hazard

  Any location on the vehicle which possesses a fuel to which a fire could spread is considered a secondary hazard.

There are eight major locations on the vehicle which can be considered either a primary or a secondary hazard. They do, however, pose varying degrees of severity from a fire standpoint. For this reason, a fire hazard rating system has been developed. (See page 57).

Table 23 summarizes the results of the detailed analysis that was done on each of the eight hazard areas. Upon close examination of this information, it becomes readily apparent which areas of the vehicle require protection. To further help one's understanding of why each location was evaluated

TABLE 23

HAZARD ANALYSIS

	Engine Compartment	Torque Convertor	Articulation Point	Forward Differential	Battery Compartment	Brakes (Wheels)	Dashboard	Tires
1. Primary Hazard Area (Heat sources in this area could initiate a fire. For rating values, see numbers 2, 3, 4, and 5 below)	yes	yes	yes	yes	yes	yes	yes	no
2. Extremely high surface temperatures present (greater than 500 °F)	5							
3. Moderate to high surface temperatures possible (300°F to 500°F)	2	2	1	1		1		
4. Severe electrical arcing possible					-2		-2	
5. Electrical shorts causing melting/burning insulation possible		1	1		-2		-2	
6. Secondary Hazard Area (A fire is not likely to initiate in, but could spread to this area)	2	3	2	1	1	1	-1	1
7. Spraying, or leaking hydraulic oil possible	3	1	1	1		1		
8. Spraying, or leaking diesel fuel possible	3							
9. Accumulated grease or oils present	2	2	2	1	1	1	1	
10. Hydraulic hose present	1	1	2	1				
11. Electrical wiring insulation present	1	1	1	1	3		3	
12. Accumulated debris (rags, paper, oil/dirt mixture, etc.) present	2	2	2	1	1		1	
13. Rubber tires present								1
14. A fixed F.C.S. is required to extinguish a fire	3	3	3	3				
15. A hand portable extinguisher is sufficient to extinguish a fire					1		1	
16. A fixed F.C.S. would be ineffective against a fire in this area						yes		yes
Total Hazard Rating	24	16	15	10	3	4	1	2

SUPPLEMENT TO TABLE 23
HAZARD RATING SYSTEM

Primary Hazard: We assume that a fire could start in a Primary Hazard Area because of the juxtapositioning of fuels and either extremely high surface temperature conditions or shorts due to electrical wiring failures.

The likelihood that a fire (of significant scale to involve the entire vehicle) would begin as a result of these conditions is rated as follows:

	Rating
High	5
Moderate	2
Low	1
Non-Existent	-2

The negative value was added to compensate for those areas which have a high potential for fire, but which could never involve the entire vehicle, i.e., the dashboard fires.

Secondary Hazard: The likelihood that a fire could spread to a Secondary Hazard Area and then proceed to involve the entire vehicle is rated as follows:

	Rating
High	3
Moderate	2
Low	1
Non-Existent	-1

The negative value was added to compensate for those areas to which a fire could spread, but which could never involve the entire vehicle, i.e., the dashboard fires.

Fuels: The fuels are rated according to their potential for being ignited in the particular area under investigation (whether it is a result of a primary or a secondary hazard).

	Rating
High	3
Moderate	2
Low	1

Fire Control System Requirement:	Rating
A permanently installed fire control system is required to extinguish a fire in this area.	3
A hand portable extinguisher is sufficient to extinguish a fire in this area	1

as shown, the following text briefly discusses the basic reasoning behind each decision.

- Engine Compartment, Transmission/Torque Converter Area, and Articulation Point

  All three of these areas are of major concern from a fire protection standpoint. Although intuitive feel may lead even the inexperienced observer to this decision, the rating totals on Table 23 provide convincing evidence to this effect.

  Since these areas provide all of the "power" which the vehicle draws on to perform its various functions, it is only reasonable to assume that they will also provide the greatest potential for fire. Both the fuels and the high temperature sources of ignition which are required to produce a major fire are present in these three areas. Also, a fire that starts in either the engine compartment or the transmission area could quickly spread to any of the other areas.

  For this reason, and because of the inaccessibility of these areas with a hand portable extinguisher, an AFCS is necessary to protect both the vehicle and the miners.

  Automatic detection is a different story. On nearly all LHD models, the operator has excellent visibility both above and to one side of all of these areas. Also, a fire is not likely to start in either the articulation point or in the transmission area unless the machine is operating, implying the driver's presence. For these reasons, it is highly questionable whether or not automatic detection in either of these two areas is necessary. The final decision concerning this question will be made as a part of the cost-effectiveness analysis later on in this study.

- Forward Differential Area

This area of the vehicle has many characteristics which classify it as a hazard. However, because of its forward location, the chance of a fire either initiating in, or spreading to this area is very remote. If a fire were to occur though, it would most likely require the help of an AFCS to bring about extinguishment.

The final decision as to whether or not this area should be protected can only be made on a cost-effectiveness basis. Later in this study, such a decision will be made.

- Dashboard and Battery Compartment

Neither the dashboard nor the battery compartment are considered a serious threat because:

1. Fires here are easily spotted by the operator.

2. A fire in either area would have little chance of occurring if the operator is not present (that is, if the machine is not running).

3. Fires in these areas are easily extinguished with a hand portable extinguisher.

4. A fire in either of these areas would have little chance of progressing into a fire of major consequence because there is very little fuel to burn, and because the source of heat can easily be removed by killing a switch.

- Wheel Brakes

The wheel brakes are a potential fire hazard because of their potential for overheating. However, the possibility of hydraulic fluid or other fuels (other than axle lubricants) reaching this area is so remote that the threat of fire is almost non-existent. Even if the axle lubricant were to overheat and catch fire, there is no way an externally mounted AFCS could extinguish it. Therefore, the wheel brakes will not be protected.

- Rubber Tires

  The only way a rubber tire could catch on fire would be as a result of prolonged exposure to a heat source, namely another fire. It is expected that the AFCS will extinguish the initial fire long before it has a chance to spread to and ignite the rubber tire. If it does not extinguish the initial fire, then the problem has gone far beyond the capability of any small system.

  An additional consideration in favor of the decision not to protect the tires is the fact that, on almost all LHD's the tires are almost completely surrounded by steel fenders. This built-in protection further reduces the chance of burning fuels or flames reaching the tires. Therefore, the tires will not be considered for protection.

5.4.2 The Fire Suppression System

- Agents

  Four types of agents are being considered for use with this system, monoammonium phosphate dry chemical, potassium bicarbonate dry chemical, and Halon 1211 and Halon 1301 gases. To determine which agent has the greater potential for the LHD application, a list of various fire extinguishing, human factors, and maintenance criteria has been established, along with an appropriate rating system. (See Table 24).

  The rating system is very simple. For a favorable aspect to each criteria, the rating value is +1. For a negative aspect to each criteria, the rating value is -1. The algebraic sum of these rating values is then used to determine the optimal agent for this application. Because of its ability to extinguish Class A, Class B, and Class C materials, monoammonium phosphate dry chemical ranks higher than the other three agents. Therefore, monoammonium phosphate will be recommended for use in this design effort.

TABLE 24

FIRE SUPPRESSION SYSTEM
AGENT ANALYSIS

Rating System: Favorable 1 Unfavorable -1	Dry Chemical		Halon Gases	
	Monammonium Phosphate	Potassium Bicarbonate	1211	1301
1. Effective against Class A, B, & C materials	Yes (1)	No (-1)	No (-1)	No (-1)
2. Clean-up required after discharge	Yes (-1)	Yes (-1)	No (1)	No (1)
3. Corrosive to vehicle components if not cleaned after discharge	Not Significantly (1)	No (1)	Not Significantly (1)	Not Significantly (1)
4. Driver visibility problem created after discharge	Yes (-1)	Yes (-1)	Yes (in high Humidity) (-1)	Yes (in high Humidity) (-1)
5. Toxic to human life	No (1)	No (1)	Yes (in high Concentration) (-1)	Yes (in high Concentration) (-1)
6. Distribution characteristics in compact/crowded vehicle compartments	Good (1)	Good (1)	Excellent (1)	Excellent (1)
7. Recharge possible without special equipment	Yes (1)	Yes (1)	No (-1)	No (-1)
8. Commercially available vehicle systems	Yes (1)	Yes (1)	Yes (1)	No (-1)
Total Rating	4	2	0	-2

- Method of Agent Containment

  There are only two commercially available methods for containing the extinguishing agent, stored pressure and unpressurized (cartridge type) units.

  To determine which has the greatest potential for overall success and acceptance in the mining environment, a list of various maintenance and environmental factors has been established, along with an appropriate rating system.

  Again, a simple rating system of favorable characteristics (rating value +1) and unfavorable characteristics (rating value -1) has been employed in the rating process. As one can see on Table 25, the unpressurized design scores much higher than does the stored pressure design. It simply is a more reliable and a more maintainable system for the underground environment. This is proven to an even greater extent when one considers that:

  1. Two of the three major manufacturers of small dry chemical systems for mobile mining vehicles have chosen the cartridge unit over the stored pressure design.

  2. In all of the mines that were visited during this contract, unpressurized (cartridge) type hand portable extinguishers were the models most often chosen for use.

  Therefore, the unpressurized design will be recommended for use in this design effort.

- Method of Agent Distribution

  Synthetic rubber hydraulic hose will be employed as the means of conveying the extinguishing agent from its container to the distribution nozzles for the following reasons:

  1. It has a high resistance to shock and vibration.

TABLE 25

FIRE SUPPRESSION SYSTEM
AGENT CONTAINER ANALYSIS

Rating System: Favorable +1, Unfavorable -1	Unpressurized (Cartridge Type)	Stored Pressure
1. Recharge possible in the mine without Special Equipment	Yes (1)	No (-1)
2. Inspection of agent possible on-site	Yes (1)	No (-1)
3. Visual inspection of tank pressure possible via a gage	No (-1)	Yes (1)
4. Adverse affects of shock and vibration on valve or release mechanisms	None (1)	Severe (-1)
5. Potential for pressure loss due to shock and vibration	Very Remote (1)	High (-1)
6. Potential for agent packing due to shock and vibration (Dry Chemical only)	Low (-1)	Low (-1)
7. The frequency of occurance of Hand Portable equipment of this type as seen during mine visits	(1) All mines visited had this type of equipment as their main source of hand portable equipment	(-1) Few mines had any of this type of equipment
Total Rating	3	-5

2. It is flexible, thus easy to install and/or replace in crowded and compact areas of an LHD.

3. It is readily available in most mines, thus eliminating the necessity of the special order of some other material (such as flexible metal tubing or small pipe).

- Nozzles

Two types of nozzles will be considered for use with the LHD AFCS. The first type produces a broad, flat-fan-shaped spray pattern. Its specific use would be in those areas where both local application and total flooding application of agent is required.

The second type of nozzle produces a conically-shaped spray pattern. It is intended for use in those areas where a direct local application of agent is most effective.

The definitions of "total flooding" and "local application" are as follows:

- Total Flooding

  This is a technique of fire extinguishment which involves simply filling an enclosed (or semi-enclosed) volume with the extinguishing agent. The net result is the smothering of all flames within that volume.

- Local Application

  This technique of fire extinguishment involves spraying the agent directly at the source of the flame in an attempt to achieve extinguishment.

5.4.3 Actuation Devices

One automatic, and two manual actuation devices will be recommended for use with this system. One manual actuation device will be located in the operator's compartment; the second will be located in a protected space on the opposite side of the vehicle. In this manner, if the automatic mode fails to actuate the system, the operator (or any other miner) can manually actuate the system from either side of the vehicle. This situation adds a greater degree of reliability to the system, and provides for a greater degree of safety in the event that access to either one side of the LHD or the other may have been blocked or obstructed.

Another safety factor that is recommended for the actuation system involves the total independence of each actuator. Any one of the three actuators will be able to initiate system discharge regardless of any failure that may have occurred with the other two.

5.4.4 Detection Devices

Types of Detection (Overview)

The basic forms of detection include smoke, flame, and heat. Smoke detectors sense the presence of aerosols or products of combustion and are generally ionization or photoelectric in nature. The ionization detector utilizes a radiation source of an Alpha or a Beta emitter to ionize the air molecules in a chamber and provide a low current source to monitor the particle content of the air in the chamber. Introduction of products of combustion particles reduces the current flow across the chamber and causes the detector to generate an alarm signal.

Photoelectric detectors incorporate a light source within a chamber and utilize either light obscuration or reflection properties of the smoke as the measurement property. The presence of particles passing through the chamber scatter light from the light source and cause a photocell to change resistance or generate a voltage to produce an alarm.

Detectors that respond to a flame receive radiated energy in the ultraviolet or infrared regions through an optical lens. The ultraviolet detectors respond to radiation in the non-visible 2200 Angstrom range. This radiation causes ionization of a trapped gas within a tube which allows a measurable current to develop a pulsed voltage output from the tube. The level of UV radiation present is proportional to the frequency of the discharges. Amplifiers are used to provide an alarm after a predetermined number of impulses or internal tube ionizations occur.

Infrared detectors respond directly to radiated heat energy, generally focused with a lens arrangement onto a structure sensitive to the 2600 Angstrom region, and in some cases the 4300 Angstrom region. The structure is usually a photocell or photoresistor element capable of producing a voltage or resistance change proportional to the level of radiation received. Dual channel infrared detectors are used to allow blindness to solar radiation and other sources in a normal ambient background which may be momentarily reflected. Thermopiles which essentially detect hot CO_2 gases have been used in this form of detection.

Heat detectors take many forms and are generally used as linear (or continuous) detectors and point source (or spot) detectors which respond to either a temperature level or a rate of change of temperature. These detectors are bimetallic strips, snap discs, eutectic salts or metals, thermistors, or pneumatic. The mode of operation in the event of an alarm condition is closing or opening of contacts, a drastic change in resistance characteristics, or the tripping of a pressure transducer.

Individual Detector Characteristics

- Smoke

  Photoelectric and ionization detectors are particularly sensitive to the air flow around the detector. These detectors have very fast response if there is sufficient air flow to allow entry of the products of combustion into the sensing chamber. In still ambient air the response time of this class of detector is very slow. A major problem associated with aerosol detectors is the decrease in sensitivity with the accumulation of a film of dust and particles within the sensing chamber. Notably, the Beta source ionization detector does not have this problem. Photoelectric detectors tend to become more sensitive and prone to false alarm with buildup of films of contaminants which appear to the detector to be an increase in obscuration level. Both photoelectric and ionization detectors require frequent periodic maintenance in the form of cleaning. The internal light source in a photoelectric detector is a frequent replacement item in the case of an incandescent light source, which is also susceptible to shock and vibration. Recent use of light-emitting diodes (LED's) has improved the characteristic lifetime of the light source.

Ionization detectors are particularly sensitive to changes in temperature and pressure even though a separate reference chamber is used. The main purpose of the reference chamber is to compensate for slow, long-term changes in ambient conditions. Rapid pressure and temperature changes can cause condensation within the chamber (a technique used by the Environment/One Corporation) resulting in a false alarm. Ionization detectors are generally suitable for fixed locations with fairly stable ambient conditions and a reasonable air movement. Ionization and photoelectric detectors are also prone to nuisance alarms when in an environment that has a high ambient particle content due to aerosols or particles not originating from a fire source. Although the detectors are responding properly to particulate matter entering the chamber in this case, particles not due to a fire condition are a cause of the high "false" or nuisance alarm rate associated with this form of detection.

- Flame

Flame detectors respond very rapidly to an open flame condition. However, they also respond to other sources of UV and heat energy and, without proper safeguards, will provide a large number of nuisance alarms. This problem is partly solved by building in a time-delay which adds to the cost and complexity and reduces the overall reliability of the detector. Build-up of contaminants on the protective lens of these detectors causes de-sensitization. UV detection is presently available that has the capability to supervise the integrity of the protective lens and modify the sensitivity accordingly. The standard method of testing integrity of the UV tube is to provide an internal UV source that intermittently tests the tube for operation. This supervision, as well as the amplification and counting of gas ionizations, provides a costly, yet fast response, form of detection. UV detectors tend to increase in sensitivity as they age and present a problem of false alarms since they become super-sensitive near the end of their useful life. This is a result of contamination of the gaseous mixture from the envelope.

Application of UV and IR detectors is generally limited to a high hazard/high risk flash fire condition which requires very fast response. Explosion suppression or protection of high flammability areas such as fuel truck loading racks and maintenance areas are typical protection areas utilizing this form of detection.

- Thermal

Fast response of thermal detectors is not realizable due to the thermal response lag associated with the sensing elements. Continuous linear detectors are capable of withstanding very high temperatures without damage and return to their normal state without degradation of operating characteristics. They have the capability of sensing a small temperature change over the entire length of the cable and of responding to and withstanding the greater than 1000°F flame temperature at a single point along its length. Thermistor core detectors require a minimum amount of passive components as an interface between the sensing phenomena and actuation of control equipment. Eutectic salt linear detectors require more sophisticated interface electronics in order to maintain an alternating current potential across the salt. This is due to degradation of the salt component over time with a direct current potential applied. Contaminants and oil film build-up on the linear detectors are not as detrimental to the operating characteristics of the thermal detectors as it is to other forms of detection. A small increase in thermal lag occurs, but is negligible when compared to the detector's normal lag.

Pneumatic, thermistor, and eutectic salt linear detector cables can withstand high levels of shock and vibration without fatigue or failure. These detectors were originally designed for rugged service in aircraft engine compartments and can withstand in excess of 60 g's shock and 2,000°F flame tests. From the standpoint of FAA recorded false alarms, pneumatic linear detectors utilizing a trapped hydrogen gas have a more stable operating characteristic than other forms of linear detectors. The linear detectors can also be bent to fit a small radius and can be installed repeatedly without failure of the cable. Stainless steel tubing swedged over a thermistor core material can be bent to a .5" radius in excess of 25 times without damage to its operating characteristics.

Some spot or point source type thermal detectors do not require additional interface or electronic amplification. The contact closures of bi-metallic strip and snap disc detectors provide the alarm signal direct and can control functions within themselves. Thermocouple type detectors require additional amplification due to the small value of voltage developed across a dissimilar metal junction. The rate-of-rise (ROR) thermal detectors can produce false alarms under conditions of unusual ambient temperature changes since most ROR detectors respond to approximately 15° per minute rise in temperature.

Basic Detection Comparisons

- Cost

  Cost comparisons on a one-for-one basis show that single point thermal detection is approximately 10%, ionization around 45%, and photoelectric about 75% of the cost of ultraviolet and infrared detection capability. Cost comparisons on this basis cannot be made with respect to continuous linear detection except in regards to a specific application. Installation costs for associated mounting hardware used with linear detection is negligible when compared to the overall cost.

For a typical vehicle installation requiring either 15 feet of continuous thermal detection or 4 point source detectors, the percentages remain the same as above but the cost of the linear detection becomes about 9% of the cost of the ultraviolet or infrared detection capability. Cost for these forms of detection can be directly related to the speed of detection.

- Complexity

The thermal form of detection is the least complex of the types of detection available. Many thermal detectors are in themselves the sensing element as well as the external controlling element. Those thermal elements that cannot directly interface with an external control require only a pressure switch, passive bridge circuit and sensitive relay, or uncomplicated amplification of the sensing signal. To provide a usable signal, ionization detectors require active isolation and amplification components between the sensing element and external control, and require circuitry to perform a memory, time delay, or verification function. Ultraviolet detectors require active timing, integrating, and threshold circuits to provide an alarm output from the sensing tube. Infrared and photoelectric detectors require active threshold and switching circuits to convert the amount of input signal directly to a control output.

- Reliability

Long-term reliability is inversely proportional to the complexity of the sensing element and its associated active and passive interface components. Since thermal detectors need no interface components, or at most only passive interface components, they are more reliable and less susceptible to physical abuse than other forms of detection. Other forms of detection require some type of active component interface such as transistors, operational amplifiers, or integrated circuits and have temperature, shock, vibration, and other environmental limitations.

Typical failure rates for UV flame detectors are around 20,000 to 30,000 hours by analysis, with false fire warning rates in the 8,000 to 10,000 hours range.

Calculated reliability data for ionization and photoelectric detectors show 100,000 to 500,000 hour Mean-Time-Between-Failures (MTBF's) and will vary between manufacturers depending on the complexity of the interface circuits used in each.

Reliability data on continuous linear detectors from field data maintained by the FAA shows that this form of detection used in a hostile, rugged environment gives in excess of 1,000,000 hours between failures or false alarms, 100 times better than UV and 10 times better than ionization detectors.

- Typical Applications

Not all of the basic detection equipment available is suitable for use in the mining environment. Varying degrees of danger to personnel exist between low risk hazards and high hazard/high risk fire conditions. Trade-offs with respect to response time to an open flame, maintenance, and false alarm rates must be considered in each application. Table 26 provides a brief comparison of the most desirable applications for each basic form of detection based on its capabilities and general operating characteristics.

- Failsafe Characteristics

Typical failures due to physical abuse or improper maintenance can cause either a false discharge or can cause a loss of capability to detect a fire situation. This leads to a failsafe question with respect to the sensing element. With respect to the

TABLE 26
TYPICAL USE WITH RESPECT TO DETECTOR CHARACTERISTICS

Detector Categories	Common Application	False Alarm Rates	Maintenance	Response to Open Flame
Thermal	Rugged, Hostile Environments			
• Point Source	Areas not sensitive to instantaneous response to fire conditions; mobile equipment	Low	None	Medium
• Continuous Linear		Very Low	None	Medium
Flame	Areas Critical to Life Safety			
• Infrared	High hazard/high risk; explosion suppression	Medium	Cleaning of Lens	Very Fast
• Ultraviolet		Medium High	Cleaning of Lens	Very Fast
Smoke	Large Area Coverage			
• Photoelectric	Storage & maintenance areas; EDP Centers	Medium High	Freq. Cleaning & Light Source Replace.	Fast, Dependent on Air Velocities
• Ionization		High	Freq. Cleaning & Sensitivity Adjust.	Fast, Dependent on Air Velocities

interface electronics mating the sensing element to the control equipment, most detectors are not fail-safe in nature in that failure of an internal component can either cause a false alarm and discharge the system or can cause a valid fire situation to be ignored. Some detectors provide a supervisory capability for some of the critical circuit components to provide a warning of detector malfunction. However, during the malfunction most detectors will not be capable of providing an alarm. In general, ionization detectors become less sensitive with age, photoelectric and ultraviolet detectors become more sensitive with age. With the latter detectors, failure of the light source or degradation of the UV tube will cause an alarm condition and is in effect a failsafe mode of operation. Disconnection of the detector equipment from its control can be prevented to some degree by using redundant interconnecting wiring, referred to as Class A wiring and operation. Although this protects the system from a single fault associated with this wiring, more than one fault can still render the system inoperative.

Continuous linear detection can provide a true failsafe operation with respect to the sensing element, should a failure occur. By providing a signal path from outer conductor end to outer conductor end, a physical failure anywhere along the detector length will not cause system failure. High temperatures due to a fire condition, even with a broken, severed, or pinched cable, will still cause a drastic change in the internal thermistor resistance or cause a conduction due to the change of state of the eutectic salt. Pneumatic continuous detection does not have this fail-safe feature since a pinched and broken line generally cannot be relied upon to contain the released gases and cause an alarm. Linear detection can also perform the detection function with several breaks in the detection line, losing capability for only the unconnected middle portion but still providing detection capability along the remainder of the loop.

In addition, due to the close proximity of a dual loop of linear detection and the high temperatures associated with an open flame, complete loss of detection capability from one linear loop will still allow failsafe operation in that the second loop will be capabile of sensing the flame condition. In any case, loss of the detection does not prevent manual actuation of the system.

- System Design Advantages

  The main concern in the design of an automatic system is the reliability of the components used in a given environment. With respect to the probability that a fire condition will be detected in an off-the-road vehicle environment, continuous linear detection is most likely to sense the fire with a minimum maintenance schedule. The rapid accumulation of particle and aerosol films in such an environment would cause rapid degradation of detection capability of other forms of detection, or cause a large number of nuisance alarms and down-time due to unwanted agent discharges.

  Without a costly preventive maintenance program, humidity and its associated corrosive conditions can also cause degradation of UV, IR and products of combustion detector operation or a large number of nuisance alarms. Open chamber detectors or optically isolated detectors cannot perform their function if closed and sealed from humidity. However, due to the method of construction and hermetic sealing, continuous linear and point source thermal detectors are inherently immune to humidity.

  Shock and vibration associated with a mining vehicle application is of major importance in the determination of a reliable detection method. Continuous linear detectors were originally designed for the aircraft industry for application in engine compartments, a hostile and rugged environment. Due to use of a stainless steel outer sheath swedged tightly over the inner core material, the continuous, linear thermal detectors are extremely rugged and can withstand in excess of 60 g's without degradation. Shock and vibration data is not generally available on other forms of detection because they are generally intended for fixed, stable installations.

Recommendations

Continuous linear detection is to be considered the best detection method for protection of underground metal and non-metal mining vehicles. From the standpoint of cost, durability, reliability, maintainability, and failsafe characteristics, this form of detection, coupled with fixed point, thermal detectors, should be used in the development of such a system.

Infrared detectors, on the other hand, should be considered for use only if the corresponding increase in cost and maintainability, and the decrease in system durability and reliability is not a major consideration.

5.4.5 <u>The Control System</u>

- Warning Devices

  For the fire condition, both a fire light and an audible alarm (minimum noise level of 100 db) will be provided to warn the driver of the emergency.

  A second warning light will be included on the control panel to notify the driver of any problem within the detection circuit. The light will receive its illumination current from a control system test circuit, to be discussed later in the "Miscellaneous Controls Section" of this report.

- Miscellaneous Controls

  There are many functions which electronics can perform. However, as the complexity of a system increases, so does its potential for failure. One way to avoid or at least minimize the possibility of failure is to design a redundancy of effort into each function to provide two or more avenues for its success. This method can inflate the cost of the system to unacceptable proportions, and can increase the complexity to a point that repair or even trouble shooting of any malfunction becomes an impossible task without special equipment and trained personnel. Therefore, in the interest of both reliability and maintainability, the functions of the control unit will be kept as simple as possible. The following text offers a thorough discussion of both the advantages and disadvantages for each of the various functions that were considered for use with this AFCS.

- Continuous System Readiness Test Circuit

  The presence of an Automatic Fire Control System is useless if the detection mode of the system is damaged or otherwise rendered inoperative. Shock, vibration, impact from flying debris, and inattentive actions of mechanics are just a few of the direct physical abuses a fire control system may have to endure daily. For these reasons, it is absolutely necessary that the control unit be designed to continuously monitor the detection circuit for malfunctions and to notify the operator of any problems if they arise.

- Control System Test Switches

  The primary reason for including these switches as a part of the system control unit is to provide the maintenance personnel with a convenient means of checking various system functions. Two separate switches will be provided; one switch will serve to test the warning devices, and the second switch will serve to check the automatic actuation device.

  The warning device test switch will be located externally on the control unit to allow for more frequent actuation. The basic function of this switch will to illuminate the visual fire and malfunction alarm bulbs, and to energize the audible fire alarm.

  The automatic actuation device test switch will be located such that only authorized maintenance personnel can activate it during scheduled yearly maintenance periods. The function of this switch will be to insure the uninhibited operation of the electronic actuation device. It should be noted that precautionary measures must be taken when activating this second switch to avoid system discharge.

- Automatic Engine Shutdown and Application of Brakes Upon System Actuation

  The pros and cons of this topic can be debated indefinitely. Few of the mine operators are interested in such a feature on their machines, while the head engineer of all three major U.S. manufacturers of LHD's, as well as this contractor, feel that engine shutdown and brake application is a firm requirement. Arguments for both sides are presented in the next few paragraphs.

- Favorable

The driver's normal first reaction to any emergency situation would be to stop the vehicle. His second reaction in a fire situation (by historical record) is to jump off and either fight the fire by hand, or go for help. In either case, he usually forgets to shut off the engine (98% of the time), and, once he leaves his seat, the brakes may no longer be set. The net effect of these actions result in a machine which not only continues to run (possibly feeding fuel to the fire via a burst hydraulic hose, fuel line, or whatever), but also one which may begin to move while totally unattended.

- Unfavorable

The mine operators expressed several major concerns:

- They are concerned that once the engine is stopped the operator will lose steering and crash into the side of a drift. (They ignore the fact that upon fuel shut-off, the normal method for turning a diesel engine off, there is a several second lag before the engine finally quits. The sputtering engine would give the driver more than enough warning to enable him to steer the vehicle clear of drifts before it comes to a complete halt).

- They are concerned that if the AFCS does not extinguish the fire, the burning vehicle could be in the escape route of other miners if it is allowed to stop just anywhere. In their opinion, the operator would drive the vehicle to a less obstructive location before stopping to get off. (They ignore the fact that if the vehicle starts on fire, historically, the driver stops wherever he is and then gets off to either fight the fire with a hand portable, or vacate the area to get help).

- There is some concern whether the brakes on the vehicle will hold if the vehicle happens to be on a grade. (The vehicle manufacturers insist that the brakes will hold).

- There is some concern that the driver may be thrown from the machine if the brakes are applied suddenly and without warning. (The mine owners do not realize that any fire large enough to be detected by the sensing elements would be visible to the driver. Also, there is a time lag of several seconds after the fire alarm goes off and prior to the application of engine shutdown/brake application mechanism. The combination of these events should give even the most inattentive operator ample warning).

Because of the serious consequences which could result if the engine were not shut down, and because the driver may be unreliable in a panic situation, it is necessary that an automatic mechanism be provided to perform the functions of shutting down the engine and applying brakes. This operation can be tied directly into the actuation portion of the system, thus achieving the same results through either the automatic or the manual modes of actuation. Therefore, this feature will be incorporated into this system's control function.

- System Time Delay, and Operator Actuated Delay/Abort Switch

Considerable thought and deliberation has been given to both of the above mentioned control characteristics. The following text will explain the purpose behind each function, and the reasons they were not incorporated into the recommended design concept.

The initial idea behind having a time delay between the detection and actuation phases of the AFCS operation was to allow the driver sufficient time to react to the fire warning devices in his efforts to stop the vehicle, turn off the engine, and then vacate the premises.

The second reason for adding a time delay to the control system was in conjunction with an operator actuated Delay/Abort switch. The original idea behind combining these two control mechanisms was to provide the operator with sufficient time to stop the vehicle, and delay the automatic actuation of the AFCS. While delaying the system, the operator could visually inspect the vehicle (from the operator's compartment) in an attempt to decide whether the fire was either small enough to extinguish without the AFCS, or whether it was just a false alarm. In either case, the Delay/Abort switch could then be used to abort the system discharge altogether.

If, however, the fire alarm was valid, the operator could simply release the spring actuated switch, and then vacate the premises. The AFCS would then proceed to actuate and discharge automatically.

There was no real consensus of opinion between the mine operators, and the vehicle manufacturers either for or against these two system characteristics. However, after considerable thought, it was decided to eliminate these functions from the recommended design concept forthe following reasons:

- Since the vehicle will automatically be stopped and the engine shut down upon system actuation (as explained previously) the operator is not involved in performing either of these functions. Therefore, there is no reason to have a time delay mechanism to allow him to do so.

- The operator Delay/Abort switch would necessitate a considerable increase in electronic control complexity, accompanied by a corresponding decrease in overall system reliability and maintainability. Also, it is the considered opinion of this contractor that although a false dump may be annoying, as well as nuisance to clean up, it can in no way harm either the vehicle, the operator, or any other individuals in the area. Furthermore, considerable confidence is held for the integrity of the detection that is recommended for use with this system, greatly reducing the probability of a false alarm.

A final consideration, which is purely speculative on the part of this contractor, shall be mentioned for the record. Historically (98% of the time), the first reaction of a machine operator in a fire situation is to attempt to extinguish the fire himself; and, almost as frequently, he is successful. However, as discussed previously this fire control system has been designed to detect and extinguish only those fires which could most likely not be extinguished with hand portable equipment. Therefore, if the detectors do sense a fire (precluding the aforementioned false alarm problem), one would not want the operator to abort the system in an attempt to extinguish the fire himself. He most likely would be unsuccessful, while giving the fire a chance to grow beyond the capabilities of the AFCS. To carry the point one step further, one must also consider the possibility of the man aborting the AFCS, attempting to extinguish the fire himself, failing in his attempt, and then turning and running without manually actuating the system. The implications of such a chain of events are catastrophic, and should most definitely be avoided.

For all of these reasons (cost, reliability, maintainability, and potential for an even greater disaster neither the time delay, nor the driver Delay/Abort switch will be incorporated into this AFCS.

Dead-Man Switch on Operator's Seat

This device was considered for use during the initial phases of the design concept. Originally, it was felt that the AFCS should operate automatically only if the driver were not in his seat (that is to say, when the vehicle was unattended).

Upon closer scrutiny, it was decided that this idea has little value to this system. The following discussion should prove adequate to defend this decision.

First of all, if the operator does spot a fire, or if he acts upon the receipt of a fire alarm, his first reaction would be to stop the vehicle, and then get up to see what the problem is. Since this action of getting up would allow the AFCS to be actuated automatically, there is no reason to delay the whole process.

Secondly, if the operator were injured and could not get off his seat, this device would necessitate the addition of some type of time delay/override mode to the control system circuitry. The complexity required, the corresponding decrease in reliability, and the added cost of such a device just seem too excessive for the questionable benefit it would provide. Therefore, the Dead-Man switch will not be recommended for use with this system.

5.5 Proposed Design Concepts

5.5.1 Presentation of Proposed Design Concepts

Five different design concepts were prepared. The sophistication and degree of complexity ranged from a manually actuated system which protects only the two most serious hazards on the vehicle (the engine compartment and the transmission area), to a highly complex, fully automatic system which protects the vehicle's four major hazard areas with a combination of thermal and infrared sensing devices. It was felt that by presenting such a diverse spectrum of system capabilities, one could more easily grasp the direct relationship between increased complexity and end-user cost.

As discussed previously, there are two major criteria which govern the design decisions for this project; i.e., the AFCS must be low cost, and it must be reliable. Not only is this stipulated in the wording of the contract, but it is also of primary importance to the mine operators who will have to pay for and maintain the systems. To comply with these demands, the systems which were recommended as the first and second choices for this particular application are not the most sophisticated of the five design concepts. They are, however, extremely reliable and effective AFCS's, and are particularily well suited for this rugged underground environment.

The basic differences between these first two systems and the remaining three design concepts lie in the area of detection. As discussed previously in this report, by excluding optical (infrared) sensors from the system, one also eliminates the need for expensive and complex time delay circuits, optical sensor check circuits, and any other support circuitry that is required to prevent the numerous false alarms which are inherent with infrared sensing devices.

In summary, the first two systems have been reduced to the lowest common denominator required to provide optimal fire protection while satisfying the criteria of low cost and reliability. They have a maximum potential for both operational reliability, and general acceptance by the Underground Metal and Nonmetal Mining Industry.

To readily facilitate a comparison between all five alternatives, a summary of the characteristics of each design has been provided in Table 27.

The various design concepts were presented to the Bureau at the Phase II Review Meeting at TCMRC at Minneapolis on April 28, 1976. At that time approval was received to proceed with design of a system in accordance with the recommended design concept.

5.5.2 Description of Approved Design Concept

This design concept is considered superior to the other four alternate systems because it provides the most durable, reliable, and effective automatic fire protection for the LHD's three major fire hazard areas (the engine compartment, transmission/torque converter area, and the articulation point).

The recommended system as described by Figures 24 and 25 has the following features:

- Protects the engine compartment, transmission/torque converter area, and articulation point.

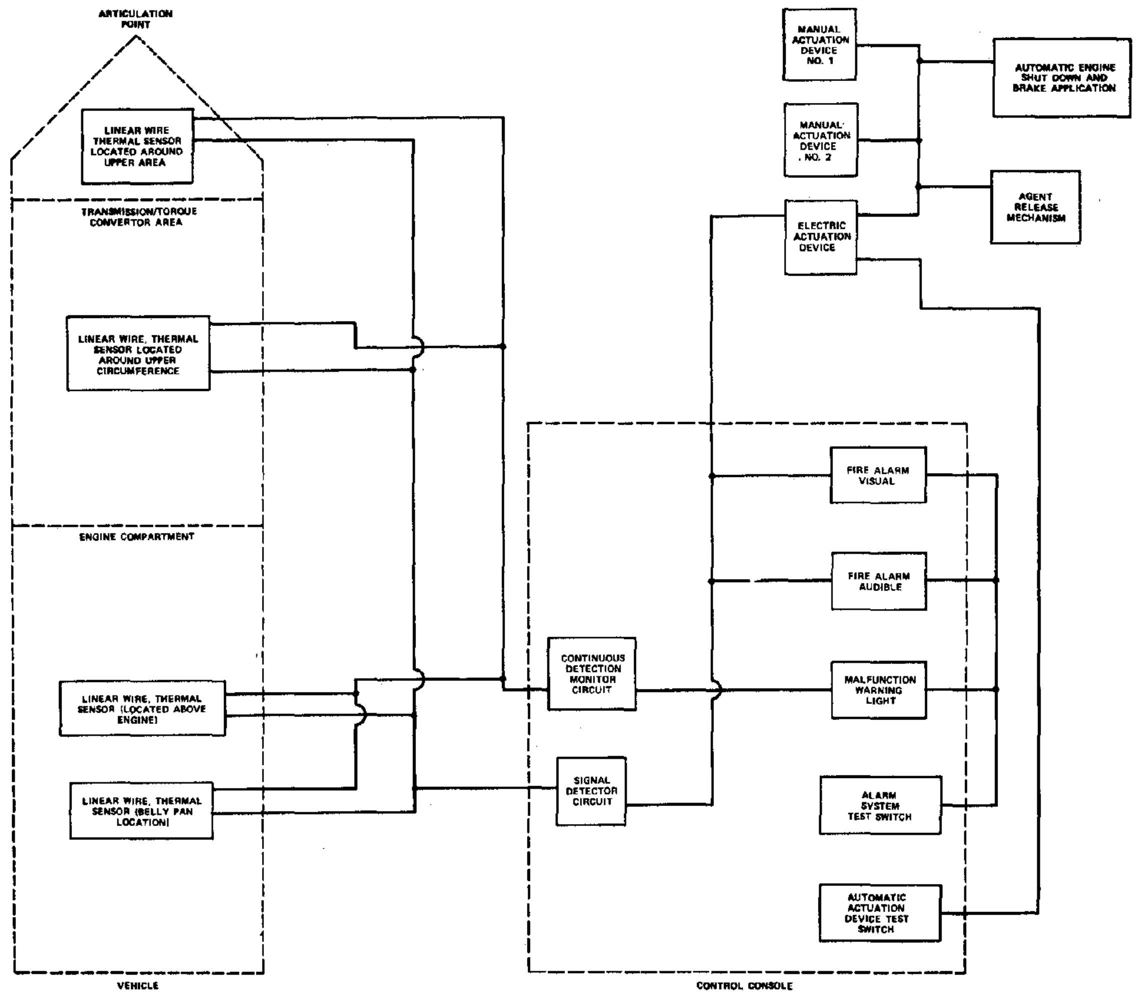
- Separate linear thermal wire detection loops in the top of the engine compartment, belly pan of the engine compartment, and transmission area.

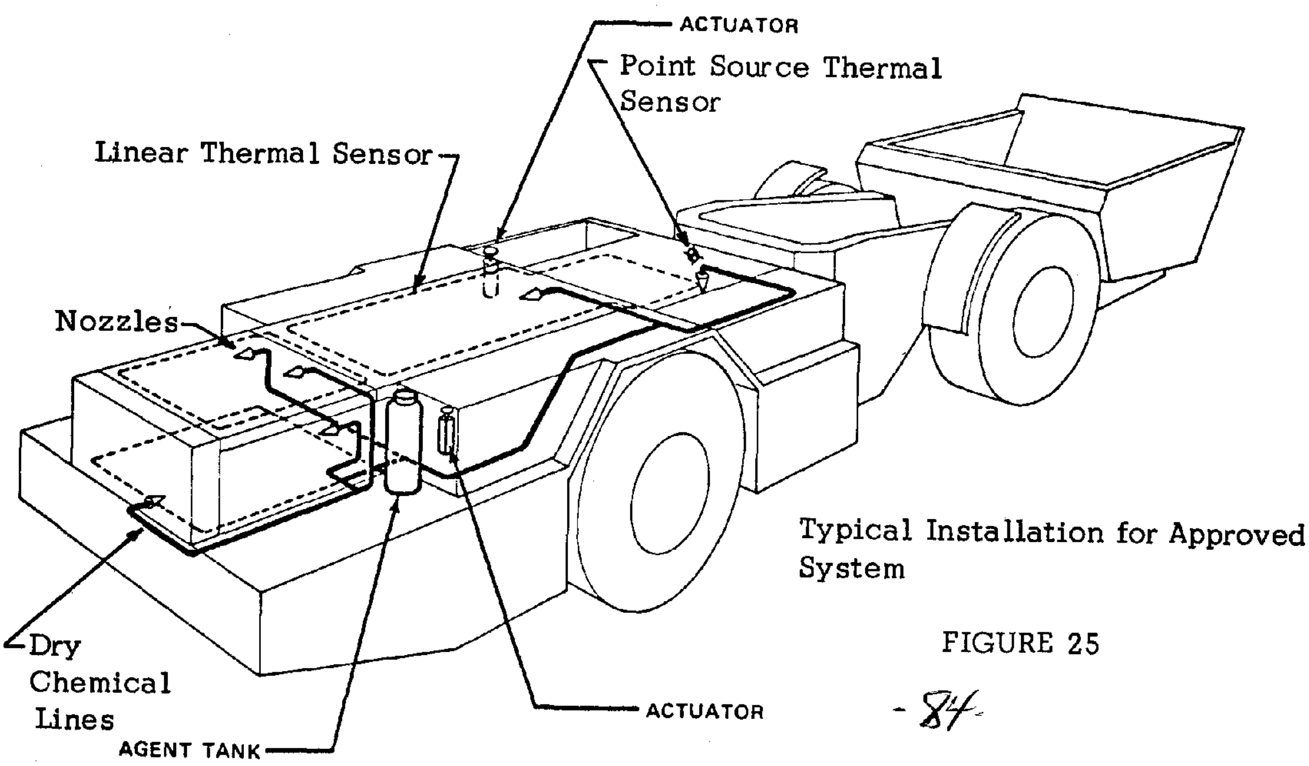
TABLE 27

Alternate Design Concepts and
Comparative Costs Analysis

	Recommended System	First Alternate	Second Alternate	Third Alternate	Fourth Alternate
		Capabilities are identical to Recommended System except for the following:			
		Protects only Engine & Transmission areas	Employs Optical & Thermal Sensors in Engine Area	Employs Optical & Thermal Sensors in Engine Area. Also, Protects Fwd. Differential Area	Manual System No Detection or Warning Devices Protects only Engine & Transmission areas
I. Hazards to be Protected					
A. Engine Compartment	Yes	Yes	Yes	Yes	Yes
B. Transmission/Torque Convertor Area	Yes	Yes	Yes	Yes	Yes
C. Articulation Point	Yes	No	Yes	Yes	No
D. Forward Differential Area	No	No	No	Yes	No
II. Detection					
A. Thermal: Linear Wire	in A, & B of I.	in A, & B of I.	in A, & B of I.	in A, B, & D of I.	none
Point Source	in C of I.	in C of I.	in C of I.	in C of I.	none
Reliability Factors: Probability of Detection	very good	very good	very good	very good	
Resistance to Humidity	good	good	good	good	
Resistance to Vibration	excellent	excellent	excellent	excellent	
B. Optical: Infrared			in A of I.	in A of I.	none
Reliability Factors: Probability of Detection			good	good	
Resistance to Humidity			very good	very good	
Resistance to Vibration			good	good	
III. Fire Suppression System					
A. Agent: Multi-Purpose (ABC) Dry Chemical	1, 30 lb. Tank	1, 30 lb. Tank	1, 30 lb. Tank	2, 20 lb. Tanks	1, 30 lb. Tank
B. Method of agent containment	Unpressurized (cartridge type)	Unpressurized (cartridge type)	Unpressurized (cartridge type)	Unpressurized (cartridge type)	Unpressurized (cartridge type)
C. Actuation: Automatic	Yes	Yes	Yes	Yes	No
Manual: Two locations, operator's compartment & one remote location	Yes	Yes	Yes	Yes	Yes
IV. Control System					
A. Warning Devices: Fire Alarm, Visual & Audible	Yes	Yes	Yes	Yes	No
Detection Malfunction Alarm, Visual	Yes	Yes	Yes	Yes	No
B. Control Features					
1. Continuous System Readiness (test) Circuit (to monitor detection circuits)	Yes	Yes	Yes	Yes	No
2. Alarm Device Test Switch	Yes	Yes	Yes	Yes	No
3. Automatic Actuation Device Test Switch	Yes	Yes	Yes	Yes	No
4. Automatic Engine Shut-Down and Application of Brakes upon Automatic and/or Manual Actuation	Yes	Yes	Yes	Yes	Yes
V. Total Estimated End-User Cost					
A. Contractor's Cost Analysis of each system					
1. Purchase Price	$1100 - 1420	$ 900 - 1220	$1640 - 2040	$2000 - 2400	$ 400 - 600
2. Installation Cost	$ 300 - 380	$ 300 - 380	$ 360 - 460	$ 400 - 500	$ 200 - 300
3. Complete System Cost (Total of 1 & 2)	$1400 - 1800	$1200 - 1600	$2000 - 2500	$2400 - 2900	$ 600 - 900
4. Maintenance (per year)	$ 200 - 220	$ 200 - 220	$ 230 - 250	$ 240 - 260	$ 60 - 80
5. Operational (Cost for one recharge and clean-up)	$ 80 - 100	$ 80 - 100	$ 80 - 100	$ 100 - 120	$ 80 - 100
B. Mine Operator's Opinion of Acceptable Costs (values as determined from survey)					
1. Purchase Price (mean value, assuming a vehicle worth of $ 100,000.)	$ 7000.				
2. Maintenance (per year) Mean value	$ 1680.				
Median value	$ 360.				

FIGURE 24
CONTROL SYSTEM SCHEMATIC FOR APPROVED SYSTEM CONCEPT





Typical Installation for Approved System

FIGURE 25

- One point source thermal detector at the articulation point.
- ABC multi-purpose monoammonium phosphate dry chemical as the extinguishing agent.
- Cartridge operated agent container.
- Hydraulic hose to convey agent from tank to nozzles.
- One electric automatic actuation device and two manually operated actuation devices (one in the operator's compartment, and one on the opposite side of the vehicle).
- Control panel in operator's compartment.
- Visual and audible fire alarms.
- Visual malfunction alarm.
- Continuous system readiness test circuit (to monitor sensors).
- Automatic engine shut down and brake application upon system actuation.
- Control system alarm device test switch.
- Control system automatic actuation device test switch

5.5.3 Method of Cost Analysis

This section of the report briefly explains the method employed to arrive at the various cost figures seen in Section V of Table 27. It must be noted that the sizing of the specific design concepts was done in the interest of obtaining a relative cost analysis, and without reference to any particular size or make of LHD.

- Purchase Price Estimates

Basic Fire Control System Components

Average cost of similar commercially-available 20-lb. system (including agent tank, brackets, nozzles, one manual actuator and agent release mechanism).	$260
Additional manual actuator	$40 (est.)
Hydraulic hose and fittings	$50-100
Electric actuation device	$90-110 (est.)

Detection & Control Devices

Thermal detection (linear) (including mounting hardware)	$6 per foot
Connectors for ends of each loop of linear thermal detector	$30 per loop
Thermal detector (point source)	$20-38 each
Thermal detection control unit	$120-140 per system
Optical (infrared) detection	$200-240 per sensor
Optical detection control unit (for two sensors)	$190-250 per system
Misc. control switches, lights, alarms, connectors, wire, etc.	$50-70 per system
Automatic engine shutdown and brake application mechanism	$100-140 per system

- <u>Installation Cost Estimates (Labor)</u>

For the fire control system	\$180-280 per system
For the detection & control components	<u>\$120-220 per system</u>
TOTAL	\$300-500 per system

- <u>Maintenance Cost Estimates</u>

Labor:		
	Monthly Inspection	2 hrs./yr.
	Semi-Annual Inspection	6 hrs./yr.
	Annual Inspection	7 hrs./yr.
	Biennial Inspection	10 hrs./yr.

TOTAL 25 hrs./yr. x \$8/hr. = \$200 per year

Materials:

Miscellaneous replacement parts	<u>\$20</u> per year
TOTAL	\$220 per year

- <u>Operational Cost (Recharge) Estimate (Assume one recharge per year)</u>

Materials (assuming no system components are damaged:	\$60-100 per year
Labor:	\$20-30 per year
TOTAL	\$80-130 per year

<u>Mine Operator's Opinion of Acceptable Costs</u>

- <u>Purchase Price</u>

The survey indicated that 7% of the vehicle purchase price would be acceptable to 50% or more of the mine operators. Assuming a \$100,000 vehicle is being protected, \$7000 would be an acceptable system cost.

- Maintenance (Per Year)

  From Page 13 of the report, the acceptable maintenance costs are as follows:

Mean $140/month x 12 months	$1680 per year
Median $30/month x 12 months	$360 per year

6.0 DESIGN AND DEVELOPMENT

6.1 System Design

6.1.1 System Description

The design concept as recommended and approved in the Phase II effort was adapted to a specific system design for a Wagner ST-2B-LHD vehicle. The system provides continuous thermistor detection cable and delivers multi-purpose (ABC) dry chemical extinguishing agent to each of the following three critical areas on the vehicle:

- Engine Compartment
- Transmission/Torque Convertor Area
- Articulation Area

Figures 24 and 25 in the design concept section continue to describe the system except for the switch from point source to linear wire detection in the articulation area. Figure 26 supplements these system schematics by showing the layout of the actuation system components.

The nozzle locations and configurations are critical to the system efficiency, and will vary somewhat with each application. For this application we are using six nozzles. Four nozzles are located in the engine area, of which one will sweep the top of the engine, one will sweep the bottom of the engine across the belly pan area, and one will sweep each side of the engine. The top and bottom engine compartment nozzles will discharge approximately $3\frac{1}{2}$ pounds each, and the side engine nozzles will distribute approximately $5\frac{1}{2}$ pounds each. The side engine areas are open and thus require more dry chemical than the top and bottom. The remaining two nozzles of the system are located in the transmission and articulation areas. The nozzles are located towards the top of each area and will discharge approximately $3\frac{1}{2}$ pounds of dry chemical per nozzle.

Figure 24 is a schematic of the control functions of the AFCS. The system performs the following functions:

- A fire in any of the three protected areas will be sensed by the continuous detection loop. The fire detection signal then simultaneously triggers both the audio and visual alarms, and the electrical actuation device which releases the fire suppression agent to each of the three protected areas.

- The system may also be actuated manually at the operator's dashboard or by a remote actuator on the side of the vehicle away from the operator.

- In addition to releasing the fire suppression agent the actuators also serve to shut down the engine by cutting off the diesel fuel supply, and apply the brake by releasing pressure from the brake pneumatic system.

- The integrity of the detection loop is continuously supervised and a warning light on the control console will indicate a malfunction.

- A test switch on the outside of the control console demonstrates that the audio alarm and the lights for the visual alarms are working.

- A second test switch will simulate a fire signal to the electric actuation device and test the operation of the suppression system. The gas cartridge for the chemical container will normally be disconnected during this test to prevent discharge of the agent. This test switch is inside the control console so that it cannot be actuated inadvertently or maliciously without physically removing the control console cover.

The described system is designed specifically for the Wagner ST-2B-LHD. However, it is readily adaptable to any of the underground diesel powered mobile vehicles.

The system design was selected on the basis of reliability and low cost. The suppression system is proven by actual experience in the design environment. The continuous thermistor detection has been proven to be reliable in millions of hours of use in the aircraft industry. Although its response is slower than other types of detection, its ruggedness, reliability, and low susceptibility to false alarm make it particularly well suited to the severe mine environment.

SCHEMATIC OF ACTUATION SYSTEM

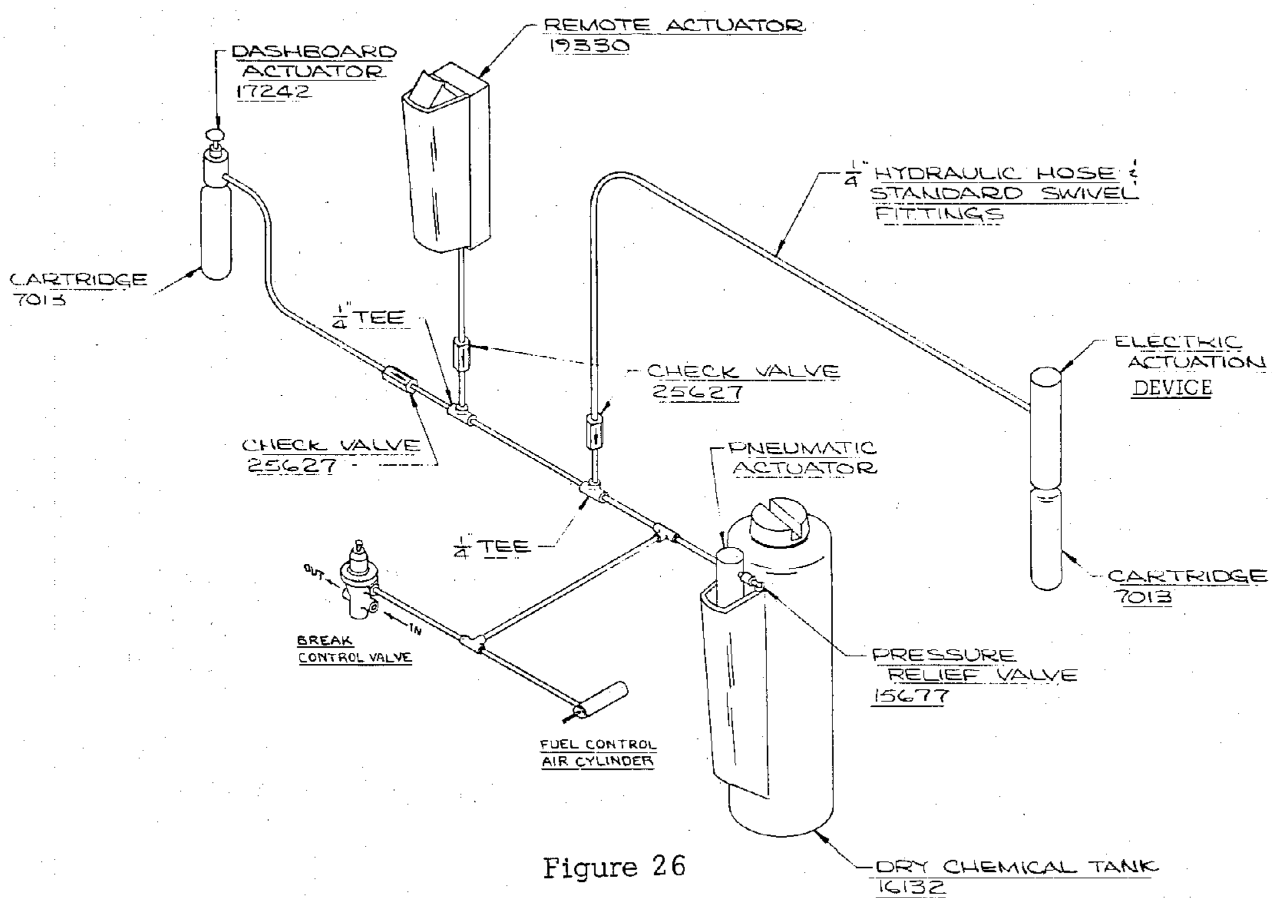


Figure 26

6.1.2 System Specification

- Detection

Linear thermistor cable, set to trigger at a temperature of 350°F at any one point on the cable.

- Fire Suppression

  Multipurpose (ABC) dry chemical, charge 27 lbs. nominal; discharge time less than 15 seconds; dry chemical stored unpressurized with cartridge pressurization.

- Actuation

  Automatic electric actuation plus manual actuation by vehicle operator, and a second manual actuation station on the side of vehicle opposite from the driver.

- Control

  Audio and visual indication of system function; visual warning of detection circuit malfunction (continuous supervision); External test switch for malfunction of audio alarm and warning lights; internal test switch to simulate fire warning and actuate system (not accessible to operator or casual personnel).

- Environment

  High humidity and severe shock and vibration loads (test per UL 299); designed for rugged handling in operation.

- Maintenance

  Requirements to be specified in Selection and Use Manual.

6.1.3 Parts List and Estimated Cost

- Detection and Control Components

Qty.	Description	Part No.
3	15' Length, Detection Cable, McGraw-Edison	244-18012-15

Qty.	Description	Part No.
2	Cable Connector (Male), McGraw-Edison	42991-24
2	Cable Connector (Female), McGraw-Edison	42990-24
4	Connector Brackets, McGraw-Edison	23693
50	Detection Cable Brackets, McGraw-Edison	23627-1
4	Jam Nut, McGraw-Edison	22922
1	Control Console (Prototype)	

- Fire Control System Components

Qty.	Description	Part No.
1	Dry Chemical Agent Tank (with pneumatic actuator and expellant gas cartridge)	16131
1	Completor Kit (consists of 1 Triple Tee; 4 Fan Nozzles; 4 Nozzle Brackets; 1 Dashboard Actuator and Bracket; 1 Actuation Cartridge; 1 Safety Valve; 1 Instruction Label)	16461
1	Remote Manual Actuator	19330
2	Actuation Cartridge	13193
3	Check Valve	25627
2	Cone Spray Nozzles	15347
2	Nozzle Brackets	16597
1	Air Cylinder (Engine Shutdown)	15521
1	Control Valve (Brake Application) Williams Air Controls; Part No. WM 147-HC	-----
1	Electric Actuation Device	Prototype
1	Agent Tank Mounting Bracket	30215

- Hose and Fittings

Qty.	Description
6'	7/8" I.D. Hydraulic Hose
21'	1/2" I.D. Hydraulic Hose

Qty.	Description
36'	1/4" I.D. Hydraulic Hose
2	7/8" Reusable Fittings
14	1/2" Reusable Fittings
14	1/4" Reusable Fittings
14	1/2" Fitting Adaptors
14	1/4" Fitting Adaptors
4	1/4" NPT Tees
6	1/2" NPT Couplings

- Total Estimated Cost to the End-User for the Entire AFCS:

Detection and Control Components	$ 753
Fire Control System Components	626
Hose and Fittings	160
Sub-Total (Component Cost)	$1539*
Estimated Installation Cost (Labor)	300
Total Estimated Cost to the End-User	$1839

*This price is an estimate of what the end-user could expect to pay for the hardware listed.

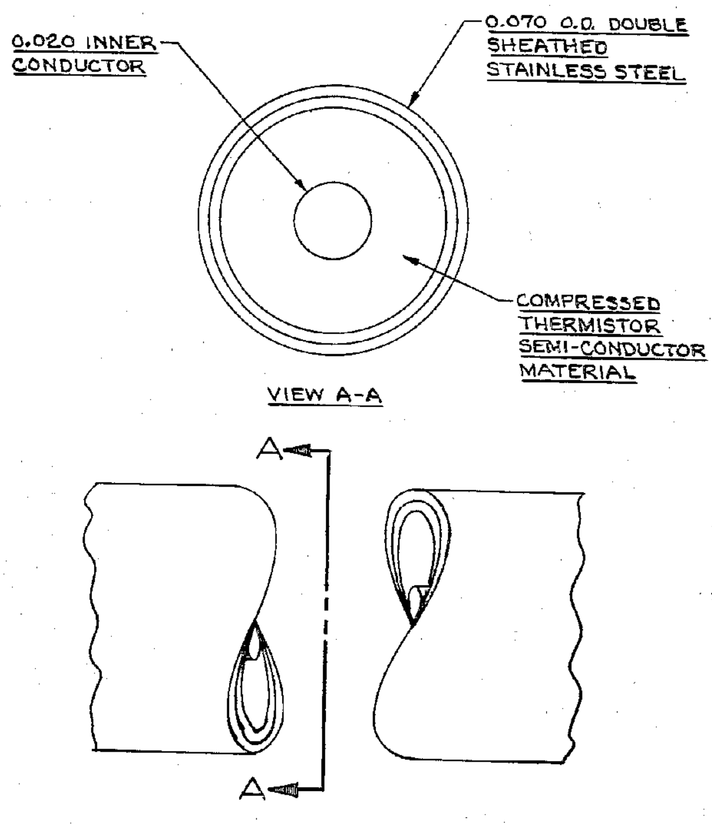
6.2 Component Selection

Specific components for the prototype system were selected following a study of the available off-the-shelf or state-of-the-art hardware, placing heavy emphasis on both reliability in the mine environment and cost. The Bureau approval of the components selected was received at the design review at Duluth, Minnesota, on January 13, 1976. In the following paragraphs the physical and functional characteristics of each component are described.

6.2.1 Detection

The detection sensing elements are continuous thermistor cable assemblies as manufactured by the McGraw-Edison Company, their Model 244-18012. This cable, commonly referred to as "Type B" cable, is used extensively in the aircraft industry and is available in several ranges of temperature sensing capability in lengths up to 30'. The cable will respond to an ambient temperature rise over the entire length of the cable or to a higher temperature rise localized at any one point on the cable.

The detector cable, diagramed in Figure 27, is a center conductor wire surrounded by a negative temperature coefficient thermistor material. This material, a manganese oxide semi-conductor, provides a very high resistance path between the inner center conductor and the outer stainless steel jacket. The outer dual-sheath jacket is swedged tightly around the semi-conductor material to

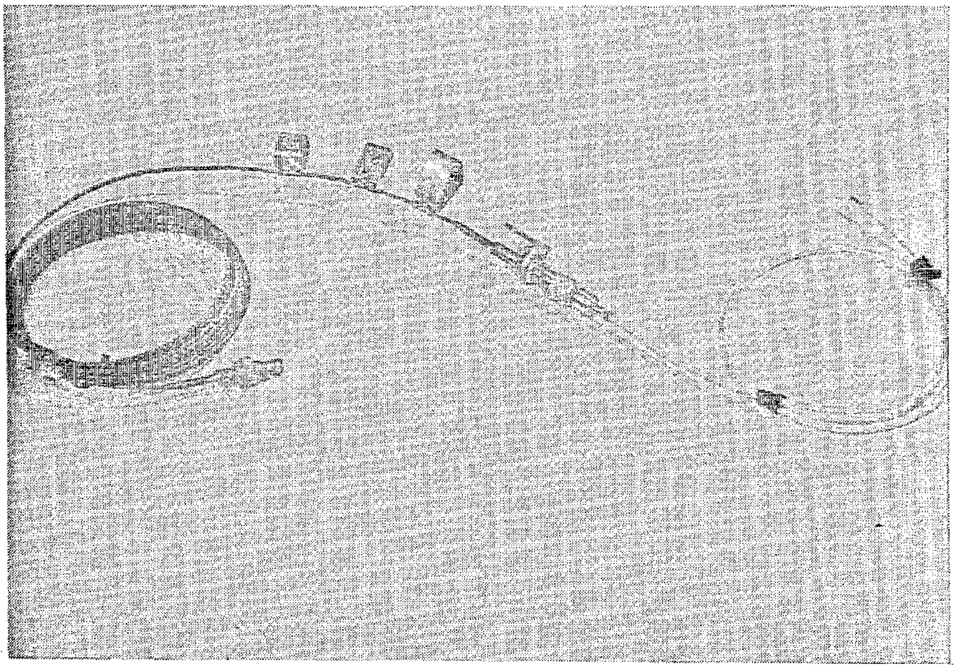


CROSS SECTION OF DETECTION CABLE
FIGURE 27

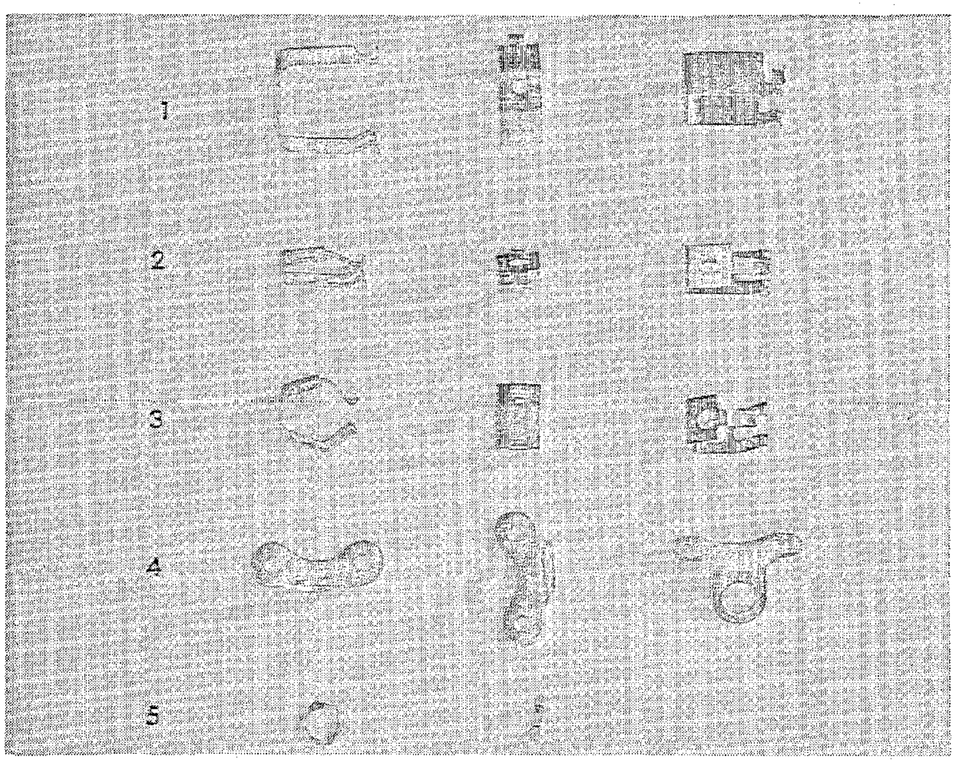
provide a nominal outer diameter of .070". This cable, shown in Figure 28, is extremely rugged in that it can be bent on a 1/2" radius in excess of 25 times without degradation of the cable. In addition, the cable can be hammered almost flat without detrimental effects to the thermistor characteristics and can withstand direct flame temperatures of 2000°F. Interconnections between lengths of cable and control unit are made with a connector which is hermetically sealed to the cable.

The fire detection system utilizes three of the 15' sections of thermistor cable in series through the critical fire areas, which can be interconnected with asbestos-wrapped heavy gauge "Firezone" wire. Measurement of cable resistance by the control console circuit is from the inner conductor, through the oxides to the outer sheath and back to the control console through the chassis mounting. The center conductor begins at, and returns to, the control console to form a continuous loop. In this manner, a single break in the detection cable still allows the system to be fully operational. The cable is supported at the connectors with a feed-through type of stand-off mounting bracket and is clamped under tension along the cable with various cable clamps every 6" to 12", as illustrated by Figure 29.

The continuous thermistor cable is the least complex of the various methods of detection available, and its characteristics are highly predictable. The response time is directly related to exposure temperature. One foot of the system's 45' of cable directly in a 1000°F flame front will cause an alarm indication within two to three seconds. This is a result of the cable's inherent five second time constant and a system alarm point setting of approximately 350°F. With proper installation of the cable through the critical hazard areas, the cable will provide adequate indication of the presence of a serious fire. Although the response is not as fast as with other possible means of detection, this disadvantage is outweighed by the ability to withstand rugged handling and extreme operating environmental exposures. Contaminant and oil film build-up on the cable will cause only a negligible lag in response time, whereas, similar amounts of contaminant would make more sensitive detectors completely inoperative.



DETECTION CABLE, FIRE ZONE WIRE, AND BRACKETS
FIGURE 28

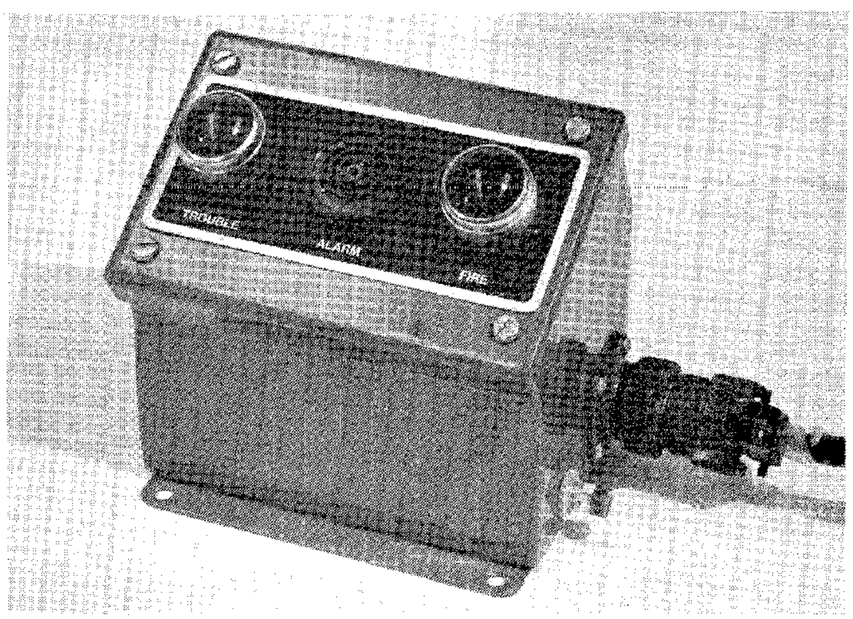


DETECTION CABLE BRACKETS
FIGURE 29

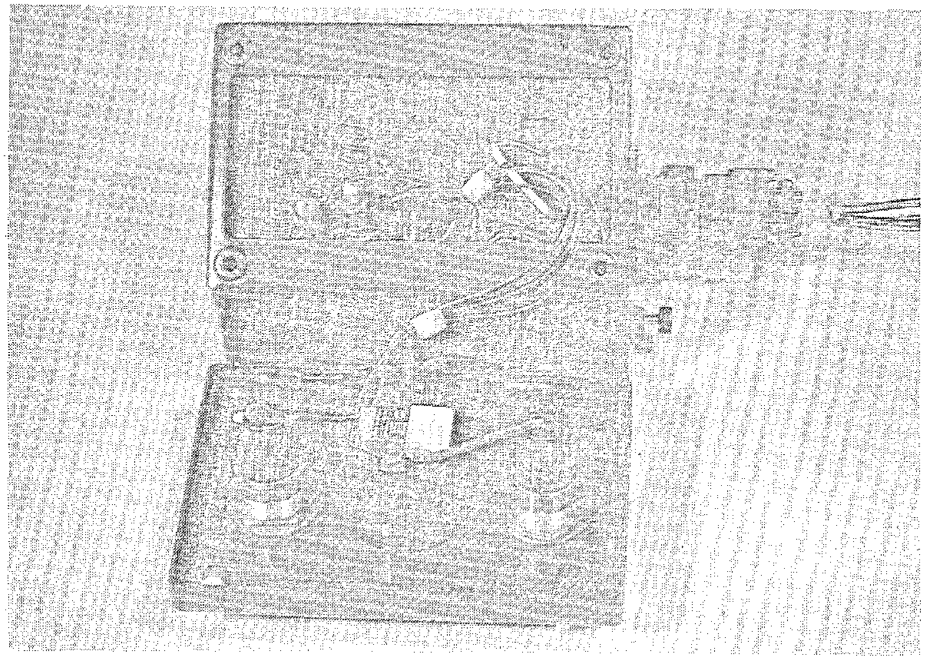
6.2.2 Control Console

The control console, as shown in Figures 30 and 31, is a small weathertight enclosure which houses a printed circuit card interface to the detection cable and a hermetically sealed momentary push button audible and lamp test switch. A type MS environmental connector allows ease of installation and provides an environmental seal for passage of system wiring. The warning and alarm indicators are mounted on a removable, gasketed access cover and are water tight bases for standard incandescent lamps. The audible alarm, also mounted on the cover, standard 85 db., 2500 Hertz frequency pulsed at a 2-5 Hertz rate to attract attention.

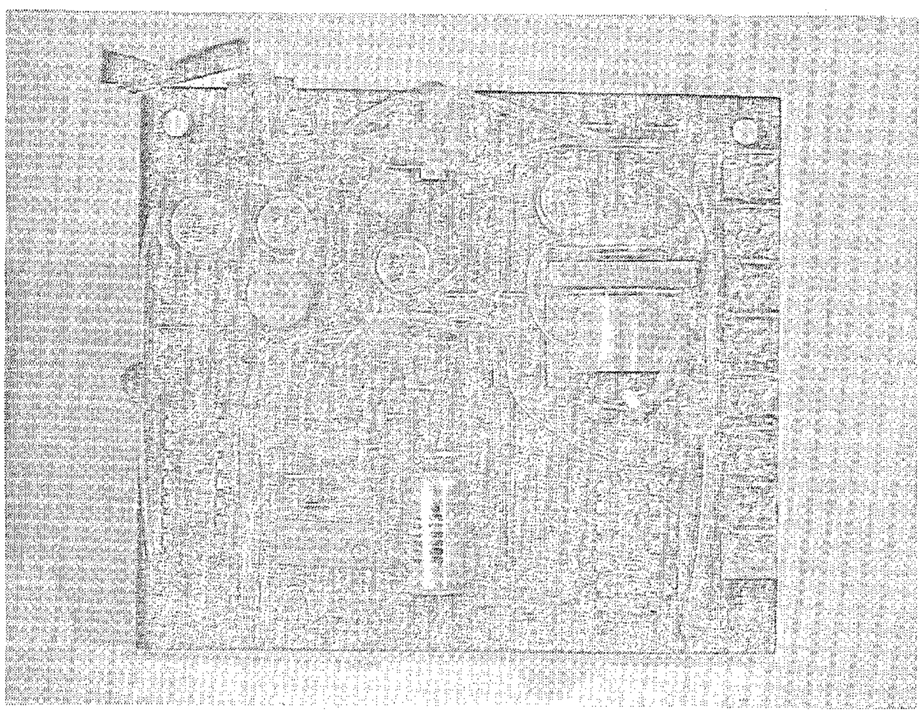
The internally mounted printed circuit card, shown in Figure 32, is a completely solid state version of the original McGraw-Edison short discriminating control unit interface for the mating Type B thermistor cable. This printed circuit card incorporates an alarm adjusting resistor for variation of the alarm trip resistance to accommodate various lengths and types of detection cable depending on the size and service of a vehicle. It also incorporates on the board a "System Test" switch to allow periodic test and operation of the entire system. Active solid state switches provide a current limited warning and alarm output to the rest of the system and include an automatic reset feature.



CONTROL CONSOLE
FIGURE 30



CONTROL CONSOLE INTERIOR
FIGURE 31



CONTROL CONSOLE - CIRCUIT CARD
FIGURE 32

Figure 33, Control System Block Diagram, and Figure 34, Control System Schematic, are included as an aid to the following detailed description of the operation of the cable interface control card.

The printed circuit module consists of two Wheatstone bridges being fed by a common signal from the detector cable. The output of the two bridges are sensed by Alarm Comparator U1 and Fault Comparator U2. The outputs of the comparators feed individual current limited transistor switches which provide the drive capability to the external warning devices. The amplifiers are interlocked in criss-cross fashion to provide only one set of conditions to be met at a time. Fault and alarm conditions cannot be given at the same time. The alarm set-point is an on-card adjustment of R5. The total resistance for the alarm is R6, a 350 ohm resistor, and the setting of R5 should be set from zero to a maximum of 650 ohms. This provides a minimum of 350 ohms and a maximum of 1000 ohms set-point to sense an overheat condition. Cable resistance below the alarm set-point and above the fault set-point will cause an alarm output. Removing the alarm condition restores the circuit to standby conditions of normally off.

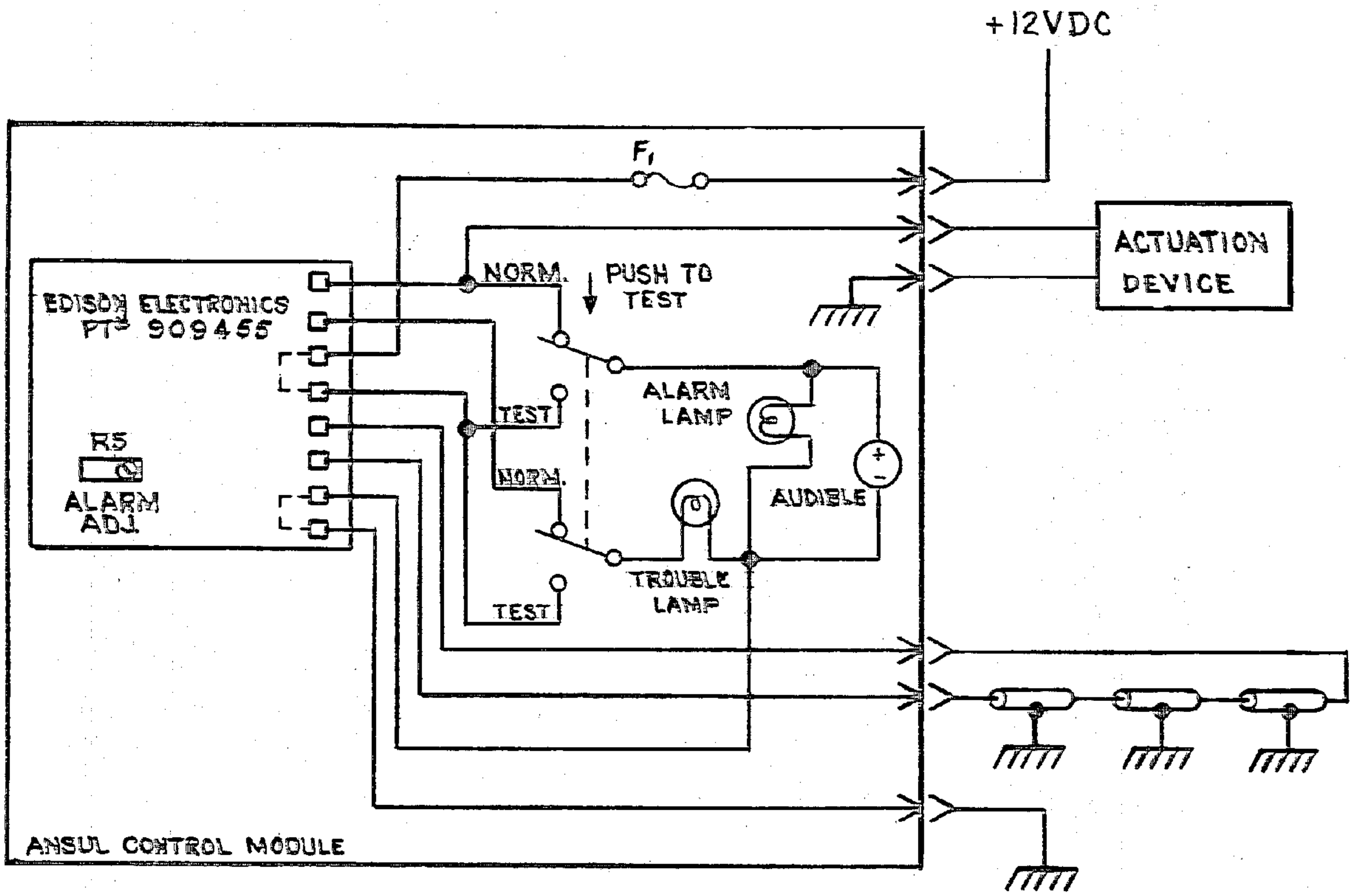
The fault amplifier, U2, operates in a similar manner. However, the time constants of the circuit are faster, permitting it to sense a fault condition, as would be the case in a shorted cable, before the alarm amplifier can react. Its interlock to U1, the alarm amplifier, prevents the rapidly falling cable resistance in this case from being seen as an alarm condition. Values of cable resistance less than 175 ohms are considered a fault condition and the fault lamp will operate. The fault set-point is established by Resistor R18, a fixed value of 175 ohms on the control module.

The control console operates directly from the vehicle battery system power, nominally +12 VDC. No internal battery back-up is provided in this control system since the power consumption of the unit is low and can be tied directly into the primary power circuit to remain active with the vehicle shutdown.

REVISIONS				
REVISION	DATE	BY	APP'D BY	RELEASE NO.

NOTE:

1. SET R5 TO "0" FOR 350 OHMS. NOT GREATER THAN 650 OHMS FOR 1K ALARM SET POINT.



DO NOT SCALE PRINT

LINEAR DIMENSIONS IN INCHES, WHEN TOLERANCES ARE NOT GIVEN, THEY ARE:

FRACTIONS ± 1/64
2 PLACE DECIMALS ± 0.02
3 PLACE DECIMALS ± 0.005
ANGLES ± 1/2°

MATERIAL

A.Q.L. DEFECT CLASSIFICATION © CRITICAL Ⓜ MAJOR MACHINED SURFACE FINISH: R.M.S. 125 IF NOT SPECIFIED.

SCALE

USED ON	DWG.	REQ'D

THE ANSUL COMPANY MARINETTE, WISCONSIN 54143

DATE APR. 13-76

DRAWN BY Hull

CHECKED BY

APPROVED BY

DESCRIPTION

BLOCK DESIGN DETECTION/CONTROL SYSTEM

REV.

LOCATION

DRAWING NUMBER - 101 - FIGURE 33

X-31255

CONTROL SYSTEM SCHEMATIC

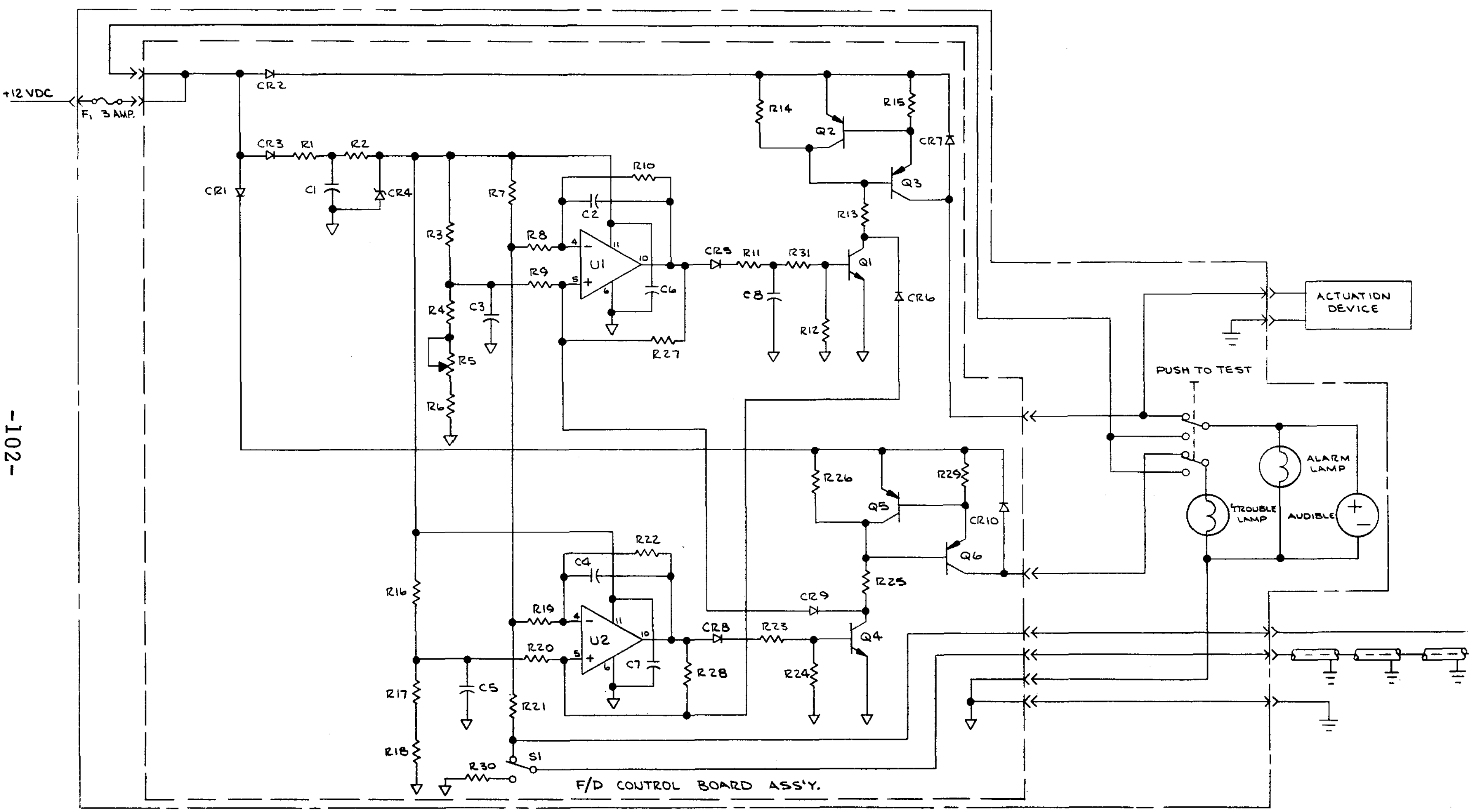


FIGURE 34

6.2.3 Electric Actuation Device

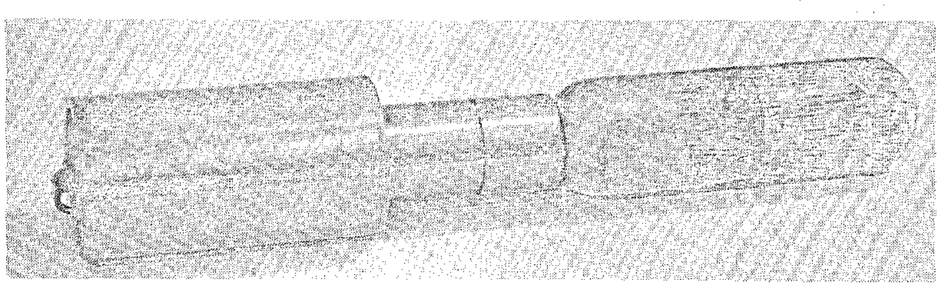
A spring-loaded magnetically latched device converts a 12 VDC signal from the detection circuit into an axial force to a puncture pin. The puncture pin, when actuated, punctures a pressure cartridge burst disc, releasing the high pressure actuation gas to the pneumatic actuator of the dry chemical container assembly. Figure 35 illustrates the electric actuation device.

The magnetic latch portion of the device is purchased from Regdon Company, Chicago. The magnetic latch is a modification of a smaller Regdon device which is now in production. An adapter has been designed by The Ansul Company to enable the mating of the magnetic latch, the puncture pin, and the high pressure gas cartridge.

The cartridge is a DOT 3A2100 cylinder charged with 1-1/8 oz. of nitrogen, Ansul Part No. 13193.

When in the armed position, a spring pressure plate provides a closed path for the lines of magnetic flux of a permanent magnet, and the magnetic force of 170 lbs. holds the armature closed against the spring force of 70 lbs. To actuate the device 12 VDC is applied to an internal coil. The lines of force around the coil buck the magnetic flux path, unlatching the device and releasing the puncture pin. When latched the margin between the 170 lb. magnetic force and the 70 lb. spring force is sufficient to hold the puncture pin in the latched position when subjected to shock and vibration loads.

The unit is sealed against moisture. On the prototype unit the external leads are potted with silicone sealant on leaving the housing, but in a production unit or connector will be mounted on the housing.

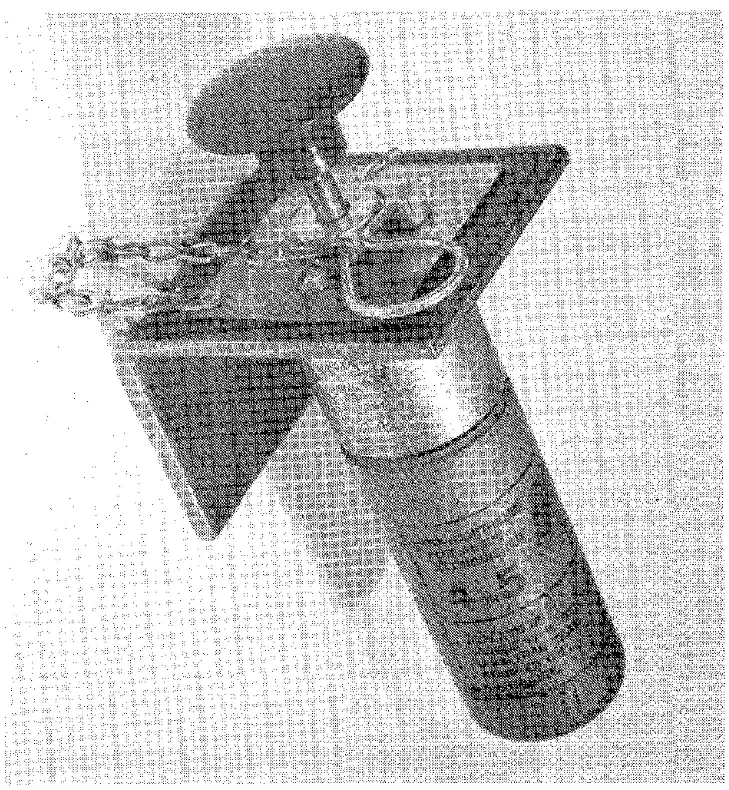


ELECTRIC ACTUATION DEVICE
FIGURE 35

6.2.4 Dashboard Actuator

The dashboard actuator, Ansul Part No. 17242, will be mounted on the vehicle dashboard. This permits the vehicle operator to manually actuate the fire protection system by removing the ring pin and depressing the push knob. This action releases the gas from the cartridge within the dashboard actuator to the actuator body of the dry chemical container. Figure 36 illustrates the device.

The nitrogen pressure cartridge, Ansul Part No. 7013, is a DOT 3A2100 cylinder charged with 27/32 oz. of nitrogen gas. The component is in service on underground mine vehicles.

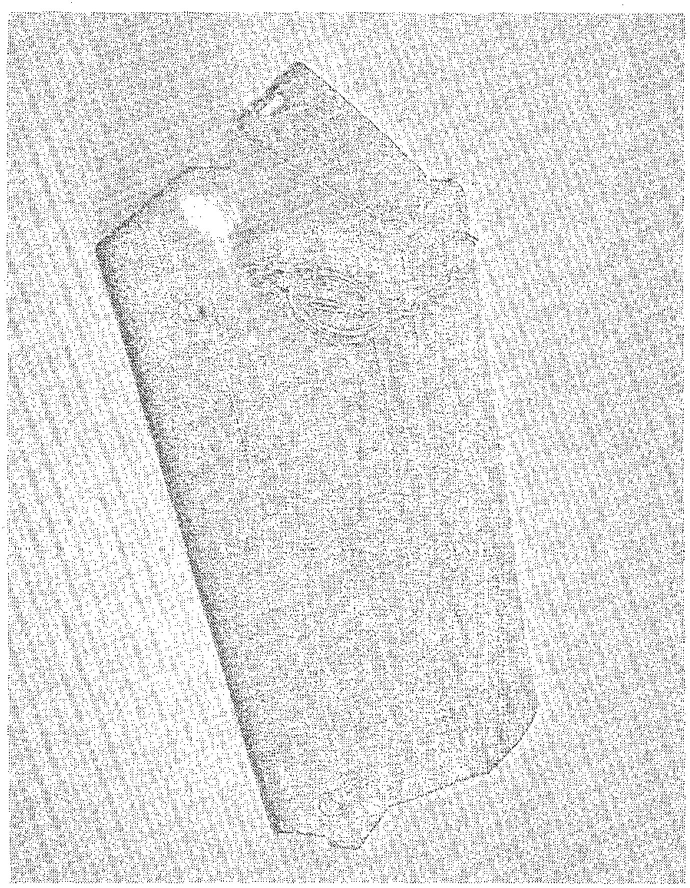


DASHBOARD ACTUATOR
FIGURE 36

6.2.5 Remote Actuator

The remote actuator, Ansul Part No. 19330, will be mounted on the side of the vehicle opposite the operator. This provides a second station for manual operation of the fire protection system. To operate, remove the ring pin and depress the puncture lever where indicated "Push." As with the dashboard actuator, this action will release the gas from the actuator cartridge to the actuator body of the dry chemical container. Figure 37 illustrates the device.

The nitrogen pressure cartridge, Ansul Part No. 6979, is a DOT 3A2100 cylinder charged with 27/32 oz. of nitrogen gas. The component is in service on underground mine vehicles.



REMOTE ACTUATOR
FIGURE 37

6.2.6 A-101 Fire Control System

The core of the fire suppression system is the Ansul A-101-30 fire control system with pneumatic actuation. This system is described by Figure 38.

When any one of the three AFCS actuation devices are employed, pneumatic pressure is applied to the pneumatic cartridge receiver actuator (Item 11). The pressure relief valve (Item 23) will automatically relieve over-pressurization in the pneumatic actuation line ($>$265 psi) and also provides a manual bleed for the pneumatic actuation system after system discharge. The pressure applied to the actuator body pushes the puncture pin (Item 16) through the seal of the cartridge assembly (Item 6), thus releasing the carbon dioxide expellant gas into the dry chemical container (Item 1). The cartridge, Ansul Part No. 12044, is a DOT 3A2100 cylinder charged with 10-1/4 oz. of carbon dioxide by weight. Upon entering the container, the CO_2 gas simultaneously fluidizes the dry chemical and pressurizes the tank. When the internal tank pressure reaches 150 psi, the burst disc (Item 4) fragments, releasing the fluidized dry chemical gas mixture into the system dry chemical distribution lines.

ANSUL A-101-10, A-101-20, A-101-30 FIRE CONTROL SYSTEMS

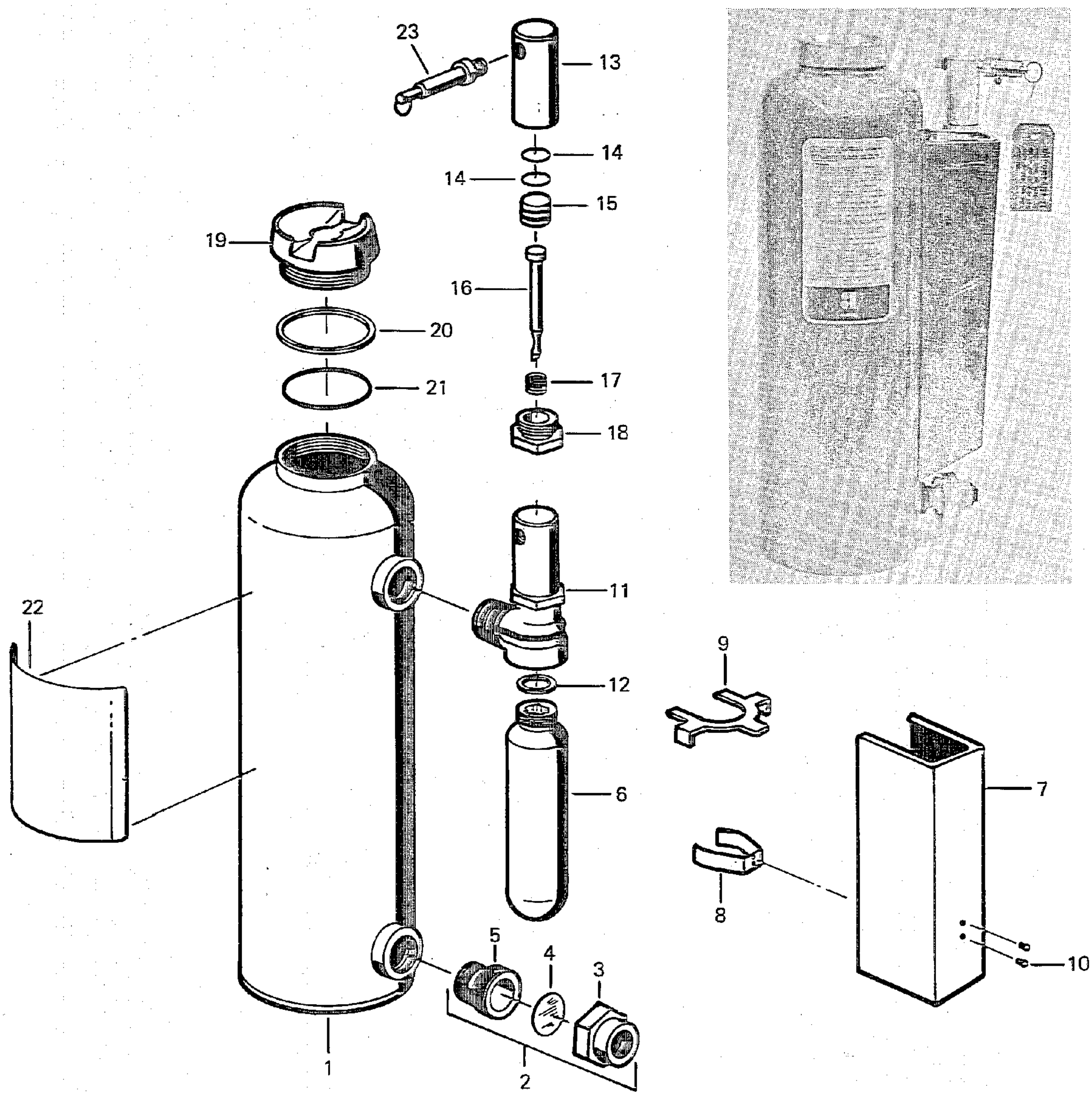
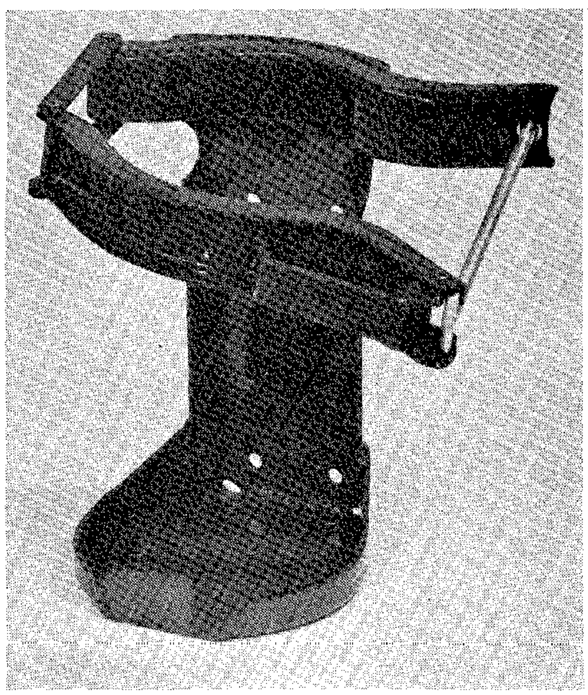


FIGURE 38

6.2.7 Mounting Bracket

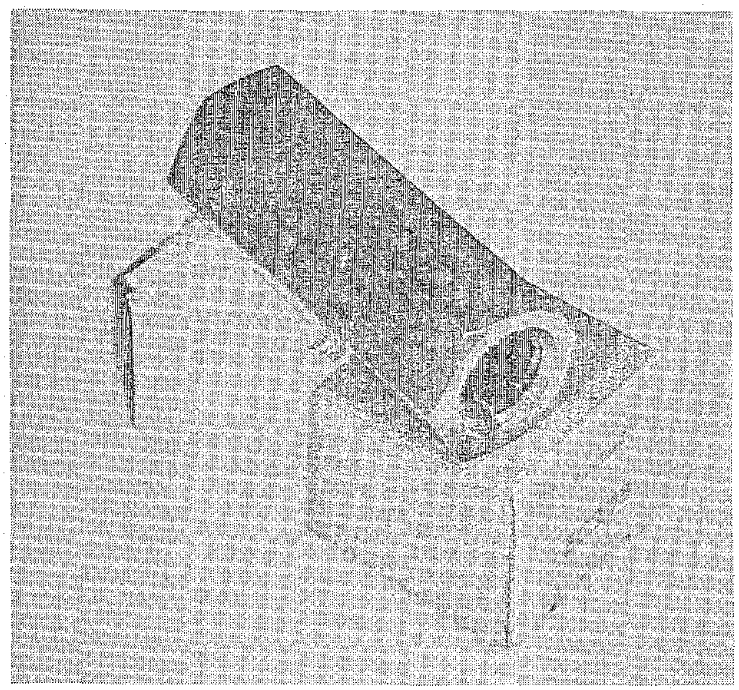
The heavy-duty mounting bracket, Ansul Part No. 30215, that is used to secure the dry chemical container to the vehicle is illustrated in Figure 39. This bracket was specifically designed to withstand the severe shock and vibration environments experienced by truck-mounted fire protection systems.



MOUNTING BRACKET
FIGURE 39

6.2.8 Check Valve

Three check valves are used in the actuation system, as shown in Figure 26. Their purpose is to limit the effective volume of the pneumatic pressure lines so that an actuation cartridge does not require the capacity to charge the complete circuit. These valves are in-line, spring-loaded, ball checks, Ansul Part No. 25627. (See Figure 40.)



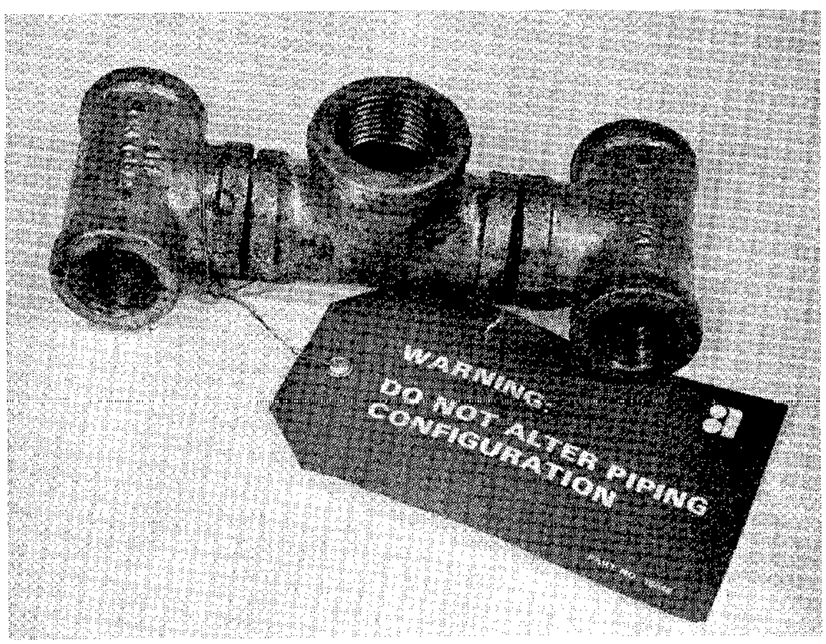
CHECK VALVE
FIGURE 40

6.2.9 Lines and Fittings

The lines which carry the fluidized dry chemical are single wire braid, textile or rubber coated hydraulic hose. All lines conform to SAE Standard J517A or J343, and all fittings conform to SAE Standard J516A. They also conform to USBM Standard 2-G. Hydraulic hose was selected because of its flexibility and ease of installation on existing equipment.

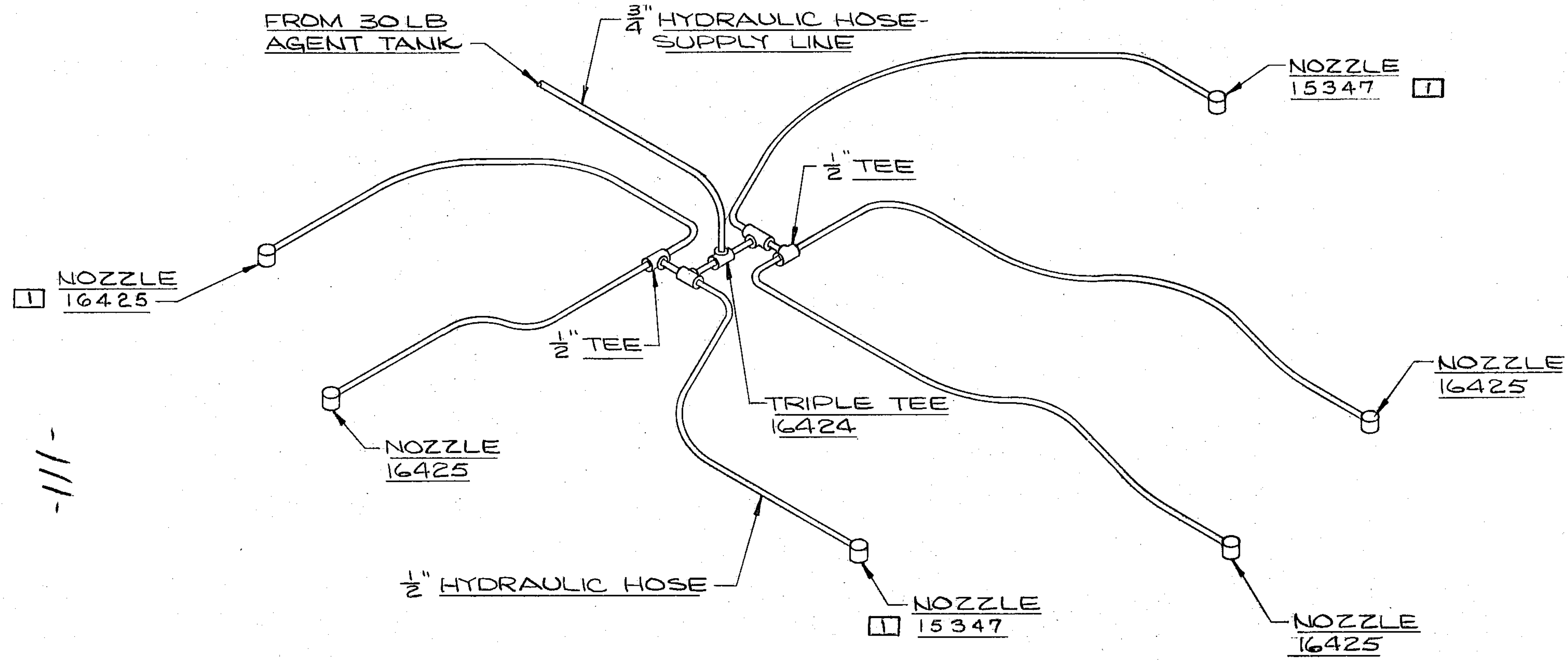
There is one special triple tee fitting, Ansul Part No. 16424, as illustrated by Figure 41. The tee assembly is assembled by the manufacturer in a fixed orientation to insure the correct distribution of dry chemical.

The line sizes and the general layout are illustrated by Figure 42. The layout shows the location of the special distribution tee and the nozzles.



TRIPLE TEE FITTING
FIGURE 41

LAYOUT - DRY CHEMICAL DISTRIBUTION LINES



NOTE:
THE MAXIMUM LENGTH OF AGENT DISTRIBUTION HOSE IS 50 FT. FROM AGENT TANK TO ANY ONE NOZZLE.

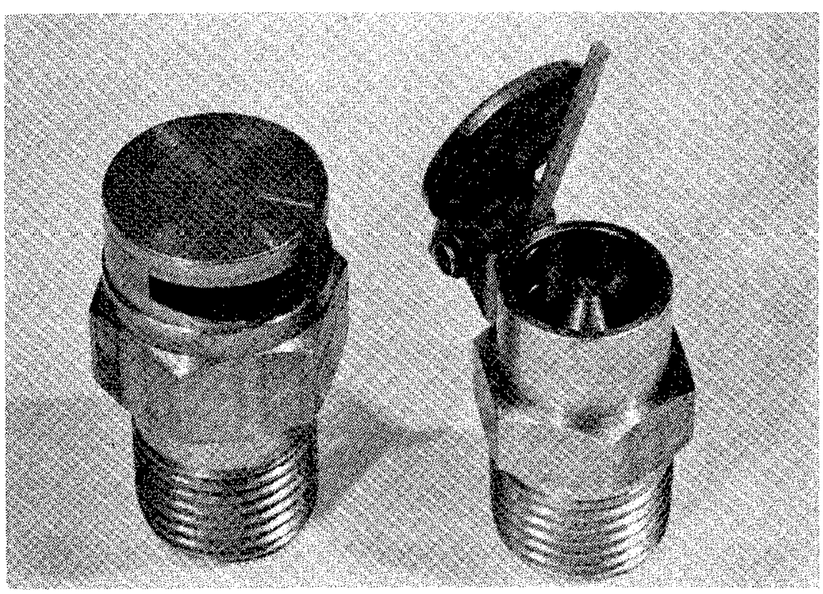
FIGURE 42

6.2.10 Nozzles

The nozzle locations and dry chemical distribution patterns were discussed in the system design section (6.1.1) and shown in Figure 25. The system includes four fan-spray nozzles, Ansul Part No. 16425, and two nozzles with conical pattern, Ansul Part No. 15347. These are illustrated by Figure 43. The fan-spray nozzles provide 180° fan-shaped pattern with coverage as indicated by Figure 44. The cone-shaped nozzles discharge a conical pattern with an included angle of approximately 30 degrees and are used on the sides of the engine.

Special nozzle brackets, Ansul Part No. 16597, are used for installation of the nozzles on the vehicle frame.

The placement and aiming of the dry chemical nozzles relative to the hazardous area is critical. Before actual installation, consideration must be given to mounting each nozzle in a position which best enables it to direct the dry chemical discharge into the total fire area. The pattern of dry chemical as it is discharged from the nozzle dictates the dry chemical coverage.



NOZZLES
FIGURE 43

FAN NOZZLE FLOW PATTERN

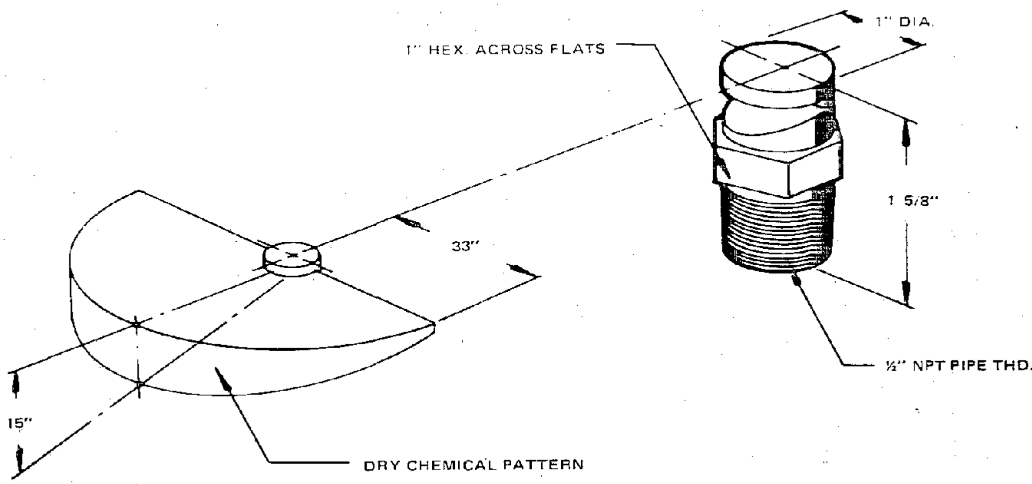
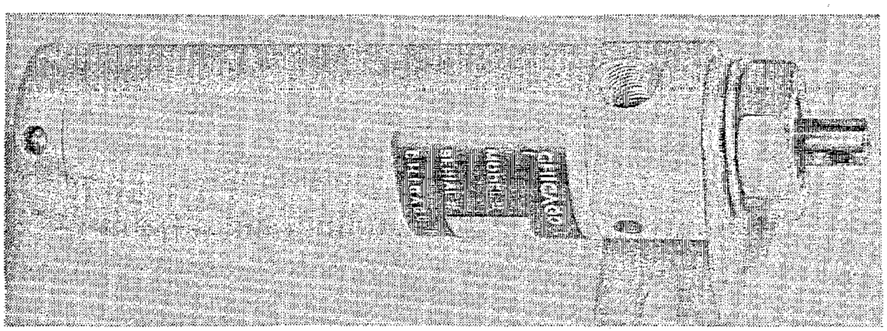


FIGURE 44

6.2.11 Air Cylinder (Engine Shut-Off)

This component is a system accessory whose function is to shut-off the fuel supply to the engine when the AFCS is actuated. It is an air piston operated by pressure from the actuation line (reference Figure 26). The fuel shut-off is a spring-return rocker arm on the side of the engine which has a cable link to the vehicle dashboard. The air piston rod will tie into this rocker arm, in parallel to, but not interfering with, the operator's cable control. The air cylinder is Ansul Part No. 15521 and is illustrated by Figure 45.



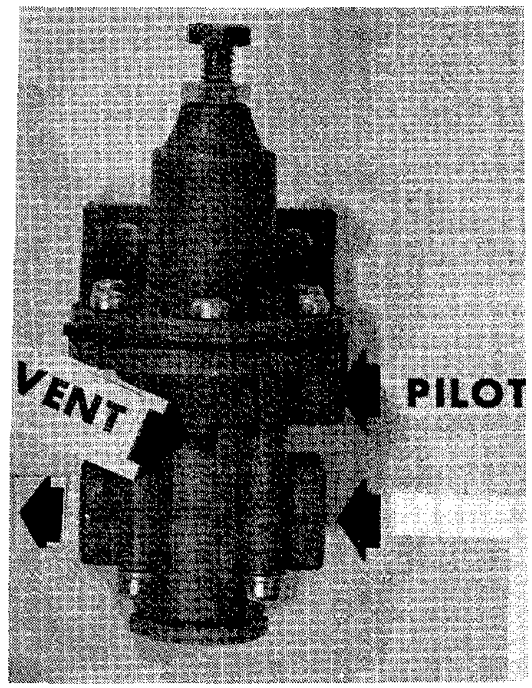
AIR CYLINDER (ENGINE SHUT-OFF)

FIGURE 45

6.2.12 Control Valve (Brake Application)

This pilot actuated valve operates within that portion of the vehicle pneumatic system which applies pressure to the hydraulic brake system. In normal operation, the vehicle pneumatic pressure is applied to the hydraulic brake system to disengage the brakes. To apply the brakes, the operator manually actuates a two-way control valve which cuts off the pneumatic pressure supply to the brakes while venting the pneumatic pressure already in the brake system. When this pneumatic pressure is relieved the brakes automatically set themselves. The AFCS simply adds a second two-way valve in series with the operator's manual brake application valve. This second valve is actuated automatically when one of the AFCS actuation devices is operated (reference Figure 26). When the actuation system pressure is applied to the pilot part of this second valve, it functions to set the vehicle brakes in the same manner as the valve in the operator's manual brake application system.

There is a time lag of several seconds after the fire alarm signal and the application of brakes. The valve (Figure 46) is purchased from Williams Air Controls, Portland, Oregon. It is a standard product of Williams Air Control and has seen extensive service in the mobile vehicle market.



CHECK VALVE
FIGURE 46

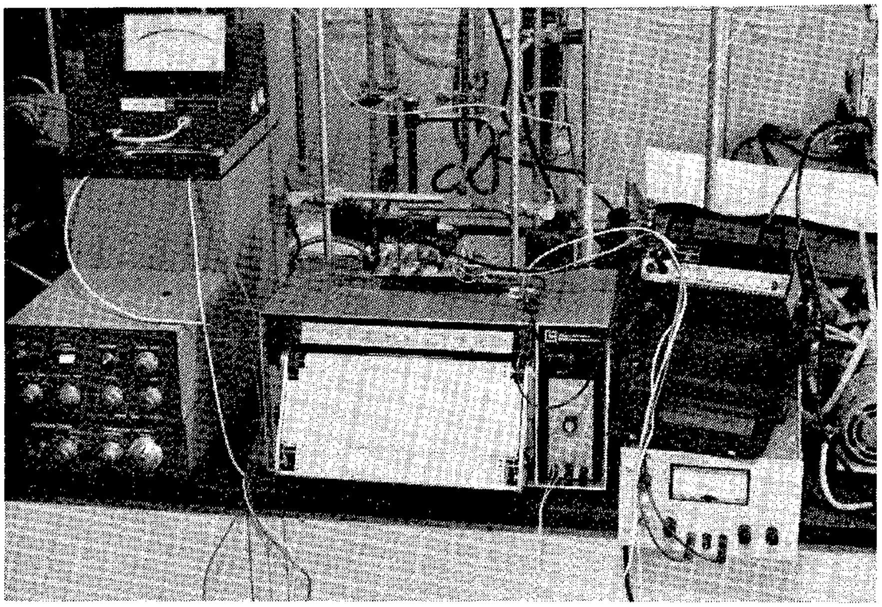
6.3 Development Test Program

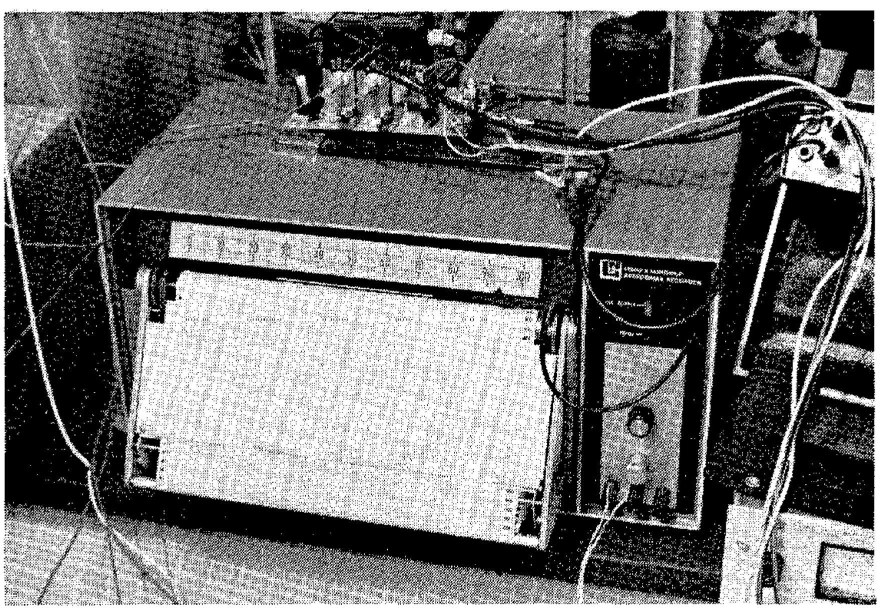
The intent of this section is to describe the history which qualifies each component for use on the prototype AFCS and to summarize the development tests performed on the vehicle mock-up prior to the field demonstration.

6.3.1 Component Evaluations

6.3.1.1 Detection

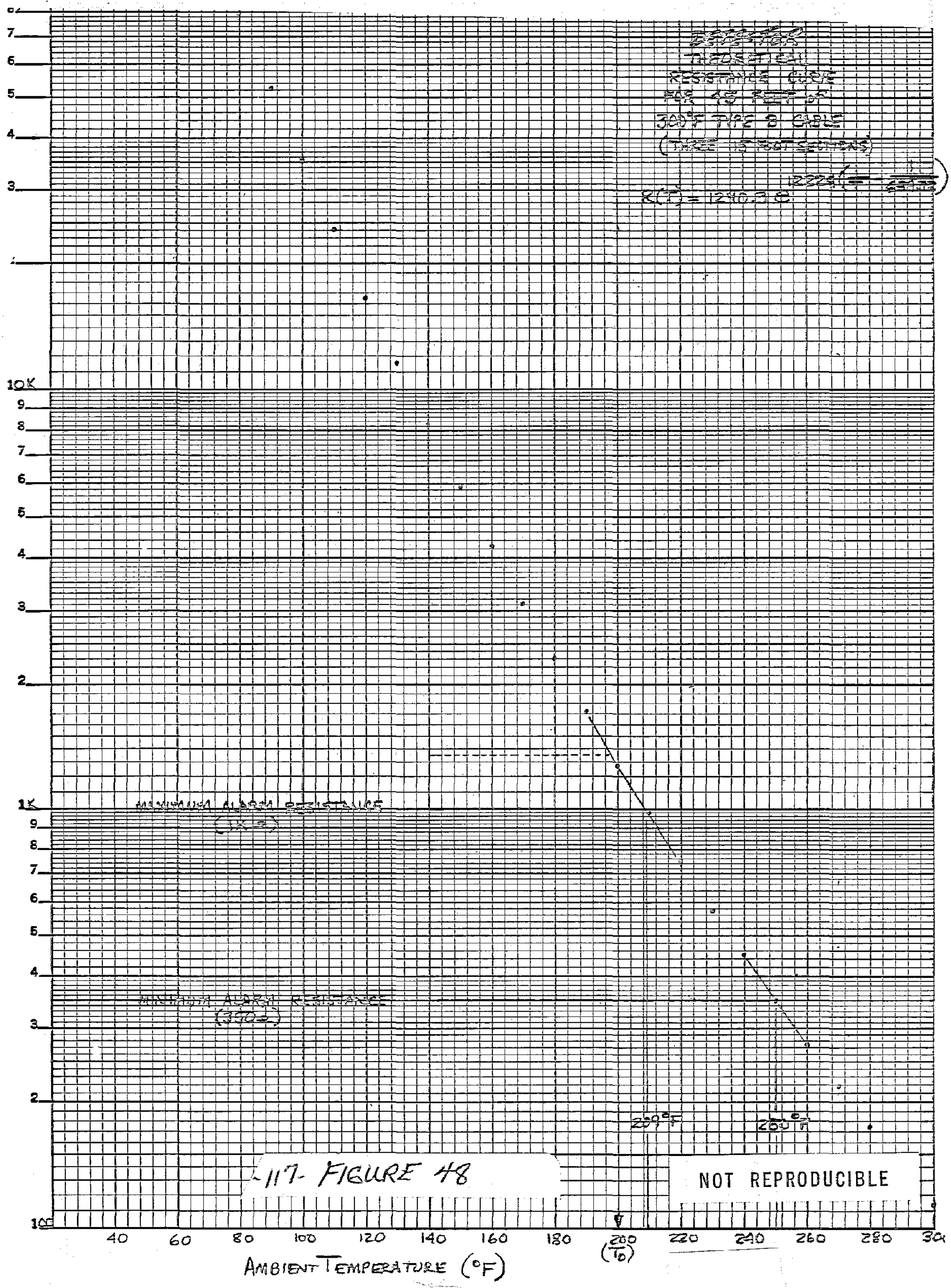
The continuous thermistor detection cable was originally developed for use in aircraft engine compartments and has been an established, proven detection method for a number of years. The high shock and vibration loads and exposure to humidity and high temperatures experienced in that environment make this cable well suited for the rugged mine environment. Extensive testing of the cable has been performed to obtain approvals by the Federal Aviation Administration prior to its selection for use on this program. These tests include shock and vibration to 100 g's, physical abuse, and extensive temperature and spot flame tests. These tests have not been duplicated for this program, but technical reports and publications are available. Testing was performed as part of this program to verify the published temperature-resistance curves for the 300°F McGraw-Edison cable. Figure 47 illustrates the test set-up for these tests. A correlation of 99.95% exists between the laboratory measured data and the theoretical curve generated by the characteristic equations developed for this device. Comparison of the data with the McGraw-Edison published curve shows a 99.98% correlation with the defining equations. Consequently, it may be concluded that the reaction of the detection cable to any given set of temperature conditions is highly predictable with respect to changes in resistance and response times. Utilizing the established data, a theoretical curve was established for three 15' sections of 300°F Type B thermistor cable describing the variation in resistance over an ambient temperature range (see Figure 48).





DETECTION CABLE - TEMPERATURE TESTS IN OVEN

FIGURE 47



-117- FIGURE 48

NOT REPRODUCIBLE

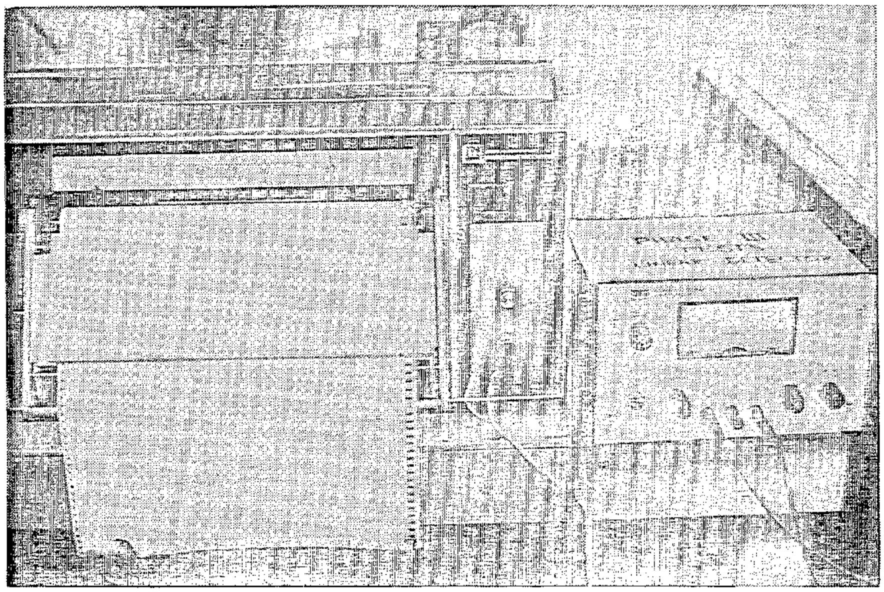
Additional tests were performed to determine the response of the detection cable when only a small section was exposed to a flame front. Figure 49 shows the test set-up which verified that the flame has to be extremely close to the cable if not directly impinging on it to produce sufficient resistance change to cause an alarm.

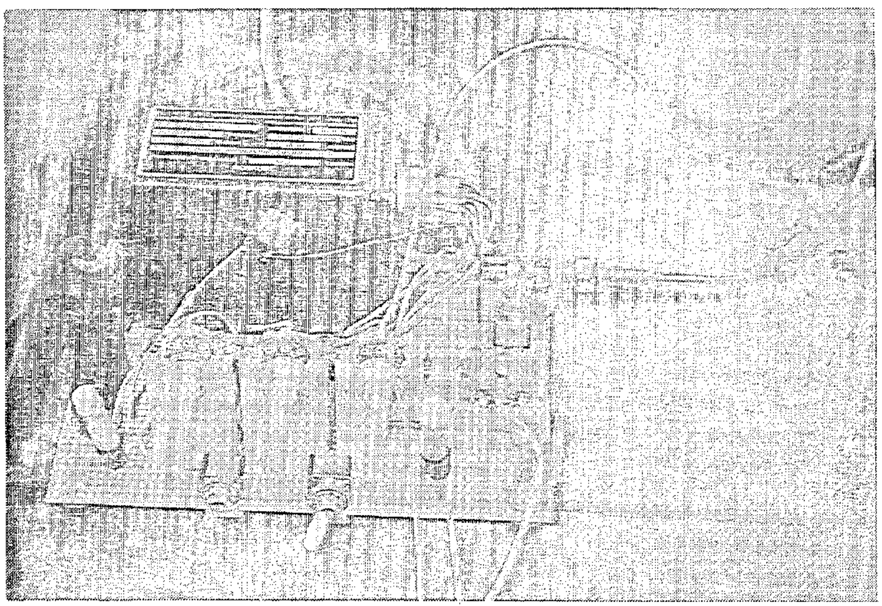
Additional oven tests were performed to simulate exposure of a short length of cable to the flame front. These tests established the resistance of the 45' section of test cable with a 12" section exposed to a stable reference temperature and simulated a localized over-temperature or fire condition. They also verified theoretical calculations of alarm resistances required to cause an alarm when a 1' section was exposed to a given temperature. Calculations can also show that the cable is extremely stable over a large ambient temperature range with no shift in actual alarm point for a small section exposed to a flame. The results of the tests provide the following accurate characterization for this system cable:

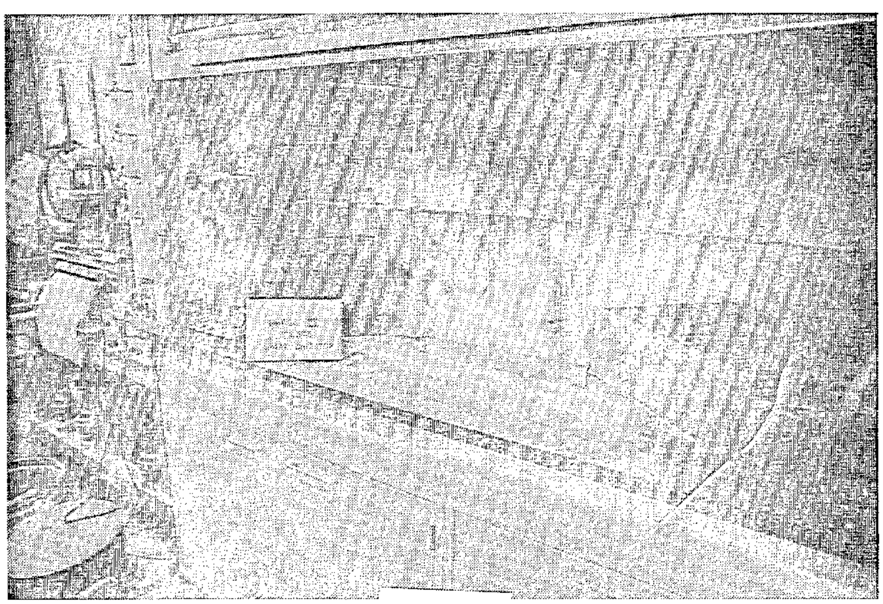
$$R(T) = A\, e^{B\left(\frac{1}{T} - \frac{1}{T_O}\right)}$$

Where: T = ambient temperature in degrees Rankine ($^{O}F + 459.72$)
R = resistance of the cable
B = semiconductor slope factor in degrees Rankine
T_O = reference temperature in degrees Rankine
A = resistance characteristic for the $300^{O}F$ cable

$$R(T) = 1290.3\, e^{12224\left(\frac{1}{T} - \frac{1}{659.72}\right)}$$







DETECTION
CABLE
FLAME
TESTS

FIGURE 49

6.3.1.2 Control Console

The printed circuit card has undergone temperature and input power testing at McGraw-Edison's facilities to ensure operation in the mining environment. The control card reliably operates over a ± 25% voltage range from the nominal 12 VDC power input (9-15 VDC) and -55°C to +71°C ambient temperatures (-67°F to +160°F). Components were selected and mounted on the basis of a high shock and vibration environment, resulting in MIL-quality design. The printed circuit card is .125" G-10 glass epoxy material, selected to minimize flexing of components or board in a mine environment.

The control console assembly has been subjected to vibration testing and exposure to a 100% relative humidity water fog atmosphere. A discussion of the results of each of these tests follows.

- Vibration Testing

  The control console was vibrated per the UL 299 specifications. Very briefly, this test sequence consists of vibrating the test specimen at a resonant frequency in each of three planes (vertical, horizontal and lateral). The duration of the vibration test is two hours for each plane. The tests are run consecutively in the order given, without maintenance to the test specimen in the interim. Prior to each sequence of testing, a thorough search is made to determine the frequency and displacement at which the vibration is most severe, this point being referred to as the resonant frequency. If no resonance is found, the specimen is vibrated through a .020" displacement, at a frequency of 60 cps. Either of these situations are considered to be "worst case" conditions.

  Both before and after each 2-hour test the unit is actuated electrically to determine its operating condition. The external test switch is employed to determine the operating condition of the lights and audible alarm, and a resistance is placed across the detection wire leads to simulate a fire condition. The results of this testing are summarized in the following table.

Plan Of Vibration	VIBRATION CONDITIONS			RESULTS OF POST VIBRATION OPERATIONAL TEST	
	Table Displacement (in.)	Frequency (Cycles per Second)	Unit Displacement (in.)	External Test Switch	Resistance Test (Fire Simulation)
Vertical	.060	19	.070	Normal Operation	Normal Operation
Horizontal	.020	60	.050	Normal Operation	Normal Operation
Lateral	.060	19	.065	Failed to operate warning light and horn. The wire leads from test switch broke off at the light and alarm terminals.	Failed to operate. A connection between a capacitor and the printed circuit board failed.

The data on the previous table indicates that the unit failed to operate properly after the sixth hour of severe vibration. There were two failures. The first occurred at the signal lamp solder connection to which a wire from the test switch is secured. The wire was not supported, allowing it to move considerably during vibration. The repeated movement eventually fatigued the wire to the point of fracture. This situation has been remedied by using slip cable ties to support the wire near the solder joint.

The second failure involved the solder joint between a condensor and the printed circuit board within the console. To correct this condition, the PCB and its components will be potted, thus preventing the relative movement which acts to fatigue the solder connections.

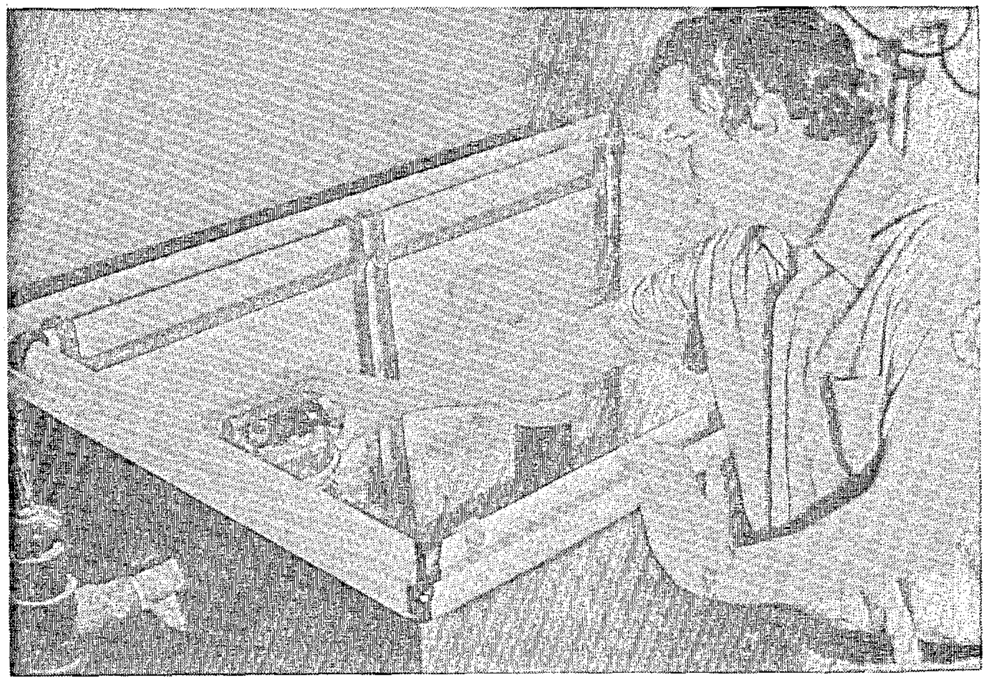
Other than the above two problems, which have been corrected, the control console functioned satisfactorily and verified the design.

100% Relative Humidity/Water Fog Atmosphere Testing

As recorded in the Phase II report of this contract, the relative humidity in underground mines varies from 25% to 100%, with the average being 78%. This phase of environmental testing was embarked upon to determine if the control console would reliably operate after prolonged exposure to a 100% relative humidity/water fog environment.

The apparatus in which the control console was tested is designed to maintain a 100% relative humidity level throughout the duration of the test period. To achieve this condition, a fine atomized fog of water is continually sprayed into the environmental chamber.

The test procedure involved placing the control console inside of the environmental chamber for



WARNING MODULE IN HUMIDITY TEST CHAMBER

FIGURE 50

a period of ten days (240 hours), see Figure 50. Each day, though, the unit was actuated electrically via both its external test switch and by placing a resistance across the detection circuit (simulating a fire condition).

After the first three days of testing it was discovered that the control console cover had not been sufficiently tightened. Considerable moisture had entered the enclosure, preventing the electrical circuit from actuating properly. The unit was promptly removed from the test chamber and air oven dried for 18 hours. After drying, the unit was tested and once again found to be operative. The cover was then replaced and securely fastened, and the entire ten-day 100% humidity test was started once again.

This second test sequence was successful. The control console operated properly throughout the duration of testing and the interior was found to be free from excessive moisture at the completion of the ten-day cycle.

In an attempt to avoid similar damage to the electrical components under actual field conditions, the printed circuit board which is contained within the control console will be potted. In this manner, all vital circuit members will be free from attack by either humidity or any other adverse environmental contaminants.

6.3.1.3 Electric Actuation Device

The device was subjected to cycling tests and environmental tests for shock, vibration, and 100% relative humidity/water fog atmosphere.

- Vibration and Impact Test

The tests were performed on three units. All units successfully completed the vibration test, including functional tests after vibration. However, Unit 3 did not successfully complete the impact test. During the test of Unit 3 the impact force from repeated 3" free drops caused the puncture pin to actuate. The unit design requires that the magnetic force holding the puncture pin shall have a margin of at least 100 lbs. over the spring force trying to release the puncture pin. The two units which completed the vibration and impact test had margins of 115 lbs., and the unit which failed had a margin of 38 lbs, which was not sufficient to hold the pin in place against the high impact load. This test demonstrated the necessity of checking the force margin during production acceptance tests.

After the vibration and impact test Unit 1 was subjected to 500 actuation cycles. It successfully punctured an LT-5 cartridge after the cycle test and the force margin holding the puncture pin to the magnet was 110 lbs. after all tests were completed, showing no measurable change.

- Corrosion Test in Humidity Chamber

  One unit was exposed to 100% humidity in the test chamber and showed signs of corrosion through the nickel plating on the body after a five-day exposure. The corrosion did not effect the function of the device. For the prototype test units, the nickel plated bodies were painted with epoxy paint used on the dry chemical container. Production units will require an improved corrosion resistant coating.

6.3.1.4 Dashboard Actuator

This device is presently a component of the manually actuated Ansul A-101-30 mine vehicle fire control system. It is approved by Factory Mutual Laboratories and has an extensive history of successful use in the underground mine environment. For these reasons, additional environmental testing is not required.

6.3.1.5 Remote Actuator

This device is presently a component of the manually actuated Ansul A-101-30 mine vehicle fire control system. It is approved by Factory Mutual Laboratories and has an extensive history of successful use in the underground mine environment. For these reasons, additional environmental testing is not required.

6.3.1.6 A-101 Fire Control System

The components used for this contract are part of a manually actuated fire control system which is approved by Factory Mutual Laboratories and have extensive history of successful use in the underground mining environment. For these reasons, additional environmental testing is not required.

6.3.1.7 Mounting Bracket

This bracket has been designed in conformance with a heavy equipment manufacturer's specifications and design criteria for tracked vehicles and then tested for a duration of ten times that specified by the manufacturer.

This testing, which was done prior to this contract, went as follows:

Frequency: Resonant Frequency Below 100 cps

Plane of Vibration	Time	Total Cycles	Equivalent Loading
Vertical	67 hours	10 million	5 g's*
Horizontal	150 hours	10 million	1 g*
Lateral	110 hours	10 million	1 g*

*1 g = force of gravity

In addition to the above test program, the bracket is listed by Underwriters Laboratories, approved by Factory Mutual Laboratories, and conforms to the following military specifications:

Vibration Testing: MIL-S-167B
Impact Testing: MIL-S-901C

Because of this extensive test program, this bracket is considered acceptable for use with this contract without further environmental testing.

6.3.1.8 Check Valve

This device is presently a component of the manually actuated, Ansul A-101-30 mine vehicle fire control system. It is approved by Factory Mutual Laboratories and has an extensive history of successful use in the underground mining environment. For these reasons, additional environmental testing is not required.

6.3.1.9 Lines and Fittings

These components are presently used as part of the manually actuated Ansul A-101-30 mine vehicle fire control system. It is approved by Factory Mutual Laboratories and has an extensive history of successful use in the underground mining environment. They also conform to SAE Standards J516A (Fittings), J517A (Hose), and J343C (Hose), and USBM Standard 2G. For these reasons additional testing is not required.

6.3.1.10 Nozzles

Both of the nozzle types used in this system are approved by Factory Mutual Laboratories and listed by Underwriters Laboratories as components of Ansul fire control systems. They are also used extensively in underground mining equipment. Thus, additional environmental testing is not required. The discharge characteristics of these nozzles were tested as part of the system tests.

6.3.1.11 Air Cylinder (Engine Shut-Off)

This device is approved by Factory Mutual Laboratories and listed by Underwriters Laboratories as a component in the Ansul Fire Control System. Further testing is not required.

6.3.1.12 Control Valve (Brake Application)

This type of valve is presently in use in several underground mining applications, and on the Wagner ST-2B-LHD the valve will be placed in series with a similar valve already performing the brake application function from the operator's dashboard. For these reasons additional environmental testing is not required.

Functional tests of the valve were performed to demonstrate its operation with expected system pressures. The tests were satisfactory.

6.4 System Mock-Up Testing

6.4.1 System Installation on Mock-Up

A full-scale mock-up of an ST-2B-LHD vehicle was designed and fabricated. The dimensions of the protected areas duplicated the vehicle dimensions so that the system discharge and fire tests would be representative of the tests to be performed on the actual vehicle later in the program. In general, the components are located in the same location planned for vehicle installation. Special care was taken to ensure that the layout of the dry chemical distribution lines and the nozzle locations would duplicate the vehicle installation.

From a fire protection standpoint, the engine compartment requires two different techniques to obtain adequate protection. The top and bottom (belly pan) of the engine compartment are fully enclosed, readily lending themselves to a total flood fire control technique. Since these volumes on this particular vehicle are relatively small, one total flood nozzle is sufficient for each location. The nozzles are mounted in the back end of their respective locations within the compartment. Their spray patterns are directed forward across the engine.

The sides of the engine compartment are a different matter. Since a fire could occur anywhere along the side of the engine, and since this area is not fully enclosed, the local application fire control technique is required. However, since the side openings of the engine compartments of most underground diesel equipment are relatively small, the turbulent flow of the dry chemical cloud, as it exits the local application nozzle, creates a combination of the total flood and local application techniques. This works in favor of the FCS for it provides a complete blanket of protection for the entire side of the engine.

Because of both the small size of this particular machine and the range that is provided by the local application nozzle being used, only one such nozzle is required to adequately protect each side of the engine. Each nozzle is located in the upper, back corner of the side opening and is directed down towards the lower front corner of the side opening. In this manner complete coverage is achieved.

It should be mentioned here that preliminary tests were run with a total flood type nozzle on the left side of the engine (side opposite the exhaust manifold). The range of this nozzle proved insufficient, therefore, the switch was made to the local application nozzle.

Both the transmission compartment and the articulation point on this mock-up were treated as total flood situations. Since these areas are almost totally enclosed and because of their small size, total flooding is the most efficient technique. Each compartment is protected with one total flood nozzle. However, the orientation of the nozzle in each compartment will be somewhat different.

The nozzle in the transmission compartment is placed in the upper, forward location with the spray pattern directed horizontally across the top of the transmission housing. The nozzle in the articulation point is also located in the upper, forward section of its compartment, but its spray pattern is directed down towards the bottom of the vehicle. The intent of this arrangement is to locally apply the dry chemical to the hydraulic hoses in the articulation area and totally flood the compartment.

It should be noted that the articulation point nozzle was first mounted outside of the mock-up articulation point compartment (see Figure 51). However, after the first few discharges it was decided that, in the interest of more closely simulating the real vehicle situation, this nozzle should be moved to the inside of the articulation point compartment.

Up to this point, only the fire control system has been described. Equally important is the analysis involving the location of the fire sensing devices, which in this case are the linear thermal detection wires. For optimal performance from this form of detection the wire should be located as close to the anticipated location of the flame front as possible. However, the rugged environment in which the underground vehicles operate also necessitates that the detection wire be protected from physical abuse.

The location which best suits both of these criteria is the upper-most interior perimeter of the compartments which are to be protected. In this location the flame front of a serious fire is most likely to reach the wire, heating it to the point of detection. Also, when attached to the interior perimeter the wire is out of the way and less likely to be damaged by direct physical abuse.

The engine compartment of this vehicle has two detection wire loops. One loop is mounted on the engine cover to protect the upper engine area. A second loop is mounted around the upper perimeter of the belly pan to provide more rapid sensing of a fire in this location. The transmission compartment and articulation point only have detection wire loops around their respective upper perimeters due to the enclosed nature of these compartments.

On a vehicle of this size and type it is wise to determine the location of the dry chemical agent tank first, for in most cases the possible locations are limited. For this particular vehicle the agent tank was located adjacent to the articulation point, on the driver's side, under the driver's control panel (see Figure 51). The agent tank bracket was not permanently mounted to the mock-up.

The next component for which a location must be determined is the primary distribution tee, or triple tee as it is called. When locating this component one must bear in mind that the lengths of hose from this tee to the various nozzles must be as close to equal as possible in order to maintain a balanced flow characteristic for the dry chemical. The location that was chosen for this component on the mock-up was inside of the articulation point compartment (see Figure 52).

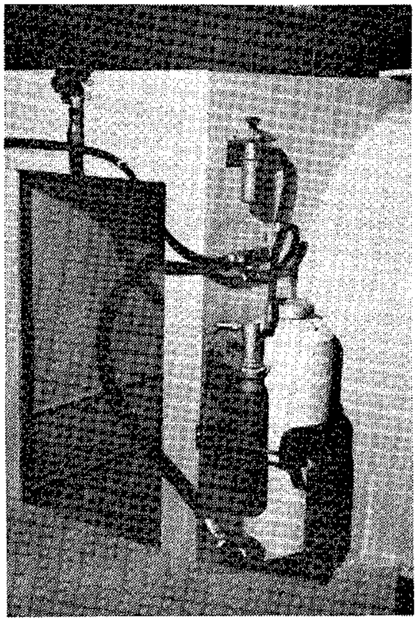
The triple tee was mounted to the mock-up with a hose clamp. After mounting the triple tee, the nozzle mounting brackets were welded or bolted in place and dry chemical distribution hose was installed (see Figures 51, 52, 53 and 54). The distribution circuit is shown in Figure 42. This arrangement was selected because it provided for a larger amount of dry chemical (approximately two pounds more per nozzle) to be discharged from the side mounted engine nozzles where one would expect the most severe fires to occur.

The fire control system actuation devices were the next components to be mounted. The dashboard actuator was placed near the driver's area (see Figure 55). The remote manual actuator and the automatic actuator were mounted on the side of the vehicle opposite the driver's area (see Figure 56). The mounting brackets for these components were bolted to the mock-up.

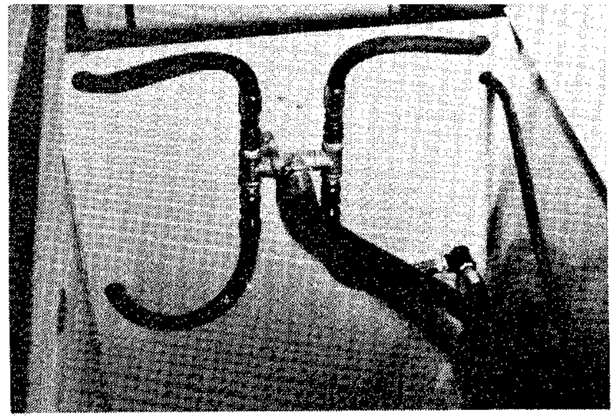
The detection wire was mounted to the mock-up by means of clamps supplied by the wire manufacturer. The clamp on Line 2 of Figure 29 was chosen because it places the detection wire as close as possible to the bulkhead of the mock-up. Figures 57, 58 and 59 show the detection wire as mounted in the upper engine compartment, transmission compartment, and articulation point respectively.

The control console is mounted in the driver's area, bolted to the mock-up bulkhead (see Figure 55). A small 12 VDC battery is used for a power supply in lieu of the vehicle battery which will be used in the vehicle installation.

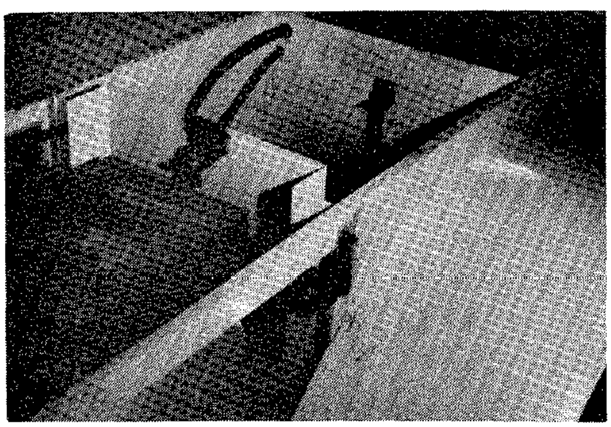
The engine shutdown device is mounted on the right side of the engine block (see Figure 60).



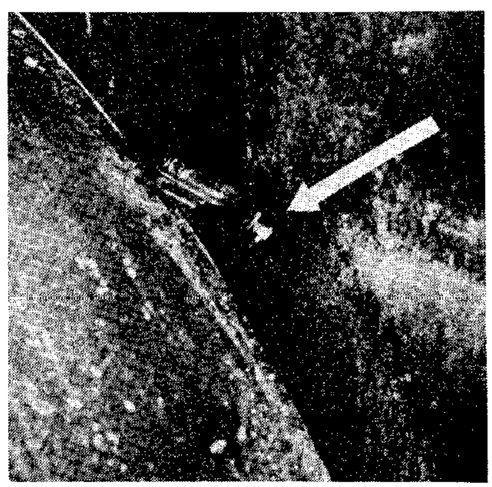
ARTICULATION POINT NOZZLE
AND AGENT TANK LOCATION
FIGURE 51



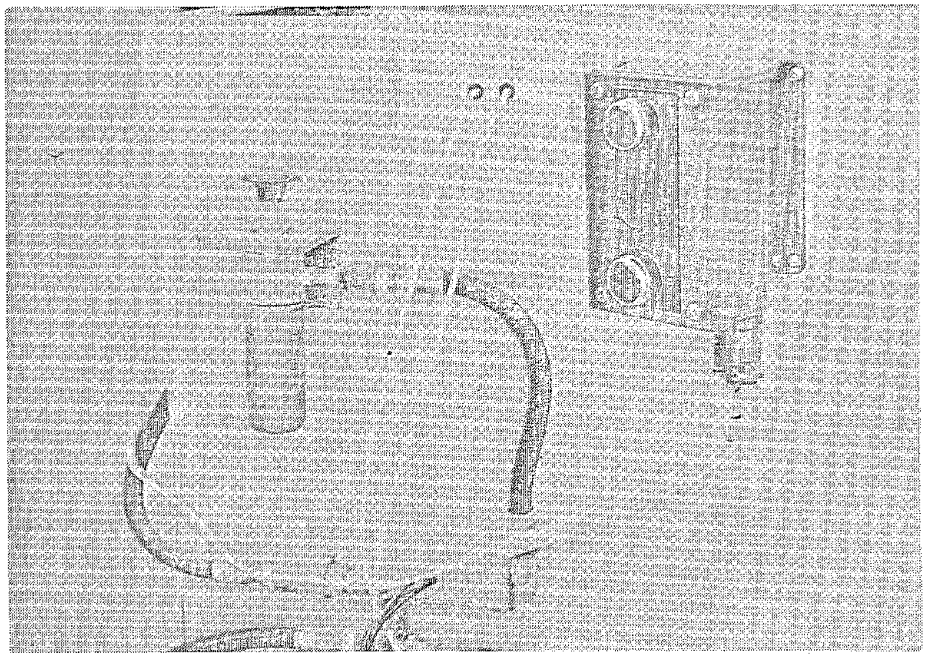
TRIPLE-TEE INSTALLED ON MOCK-UP
FIGURE 52



ENGINE (RIGHT SIDE) AND TRANSMISSION
COMPARTMENT NOZZLE
FIGURE 53

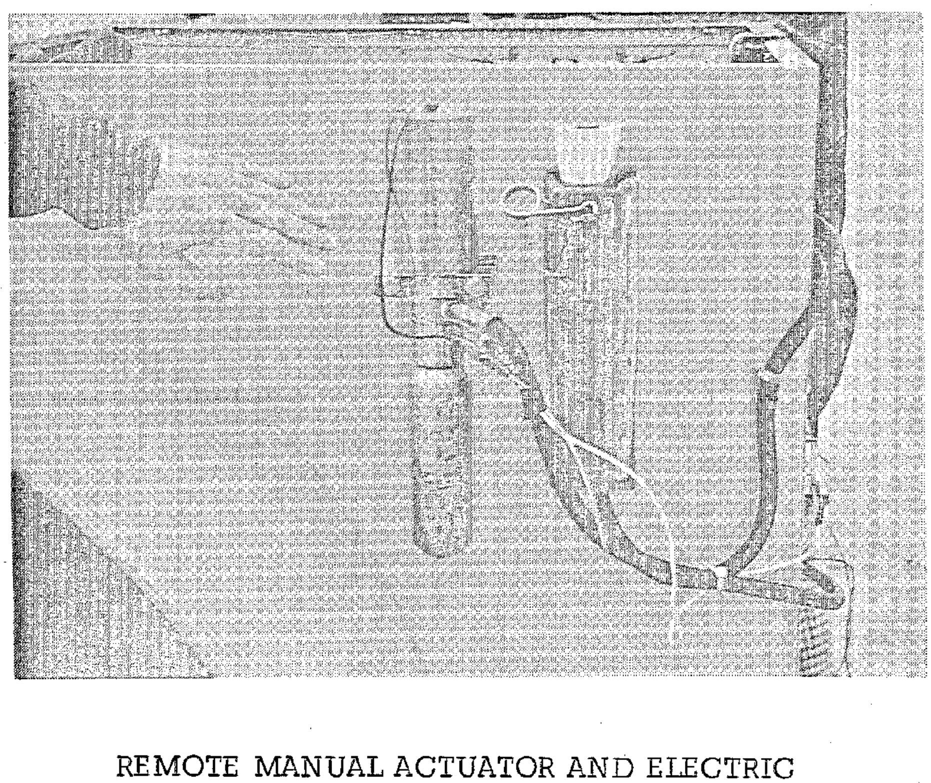


ENGINE COMPARTMENT
NOZZLE
FIGURE 54



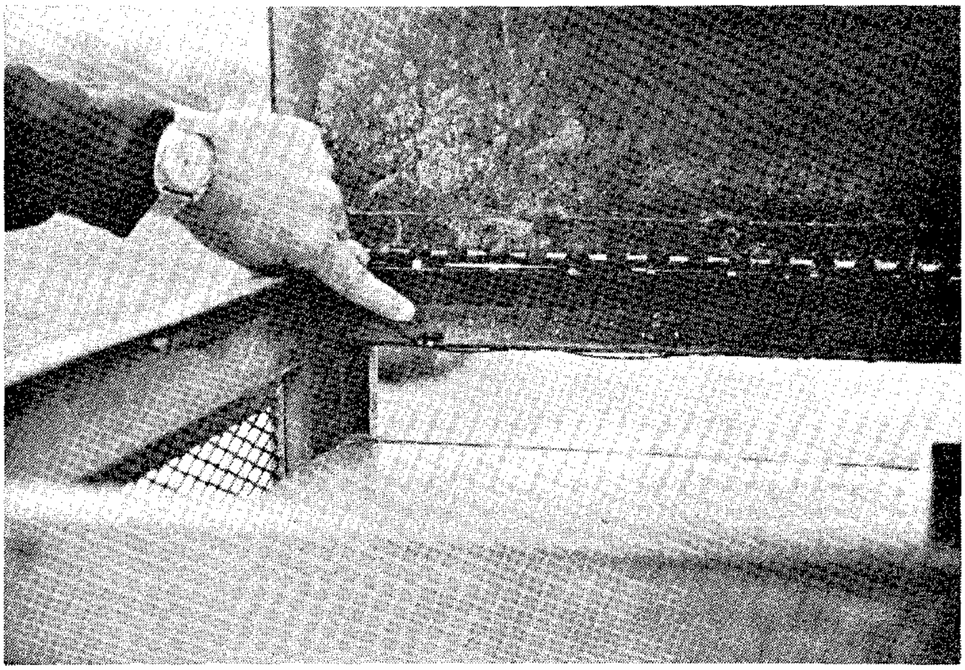
DASHBOARD ACTUATOR MOUNTED ON MOCK-UP

FIGURE 55



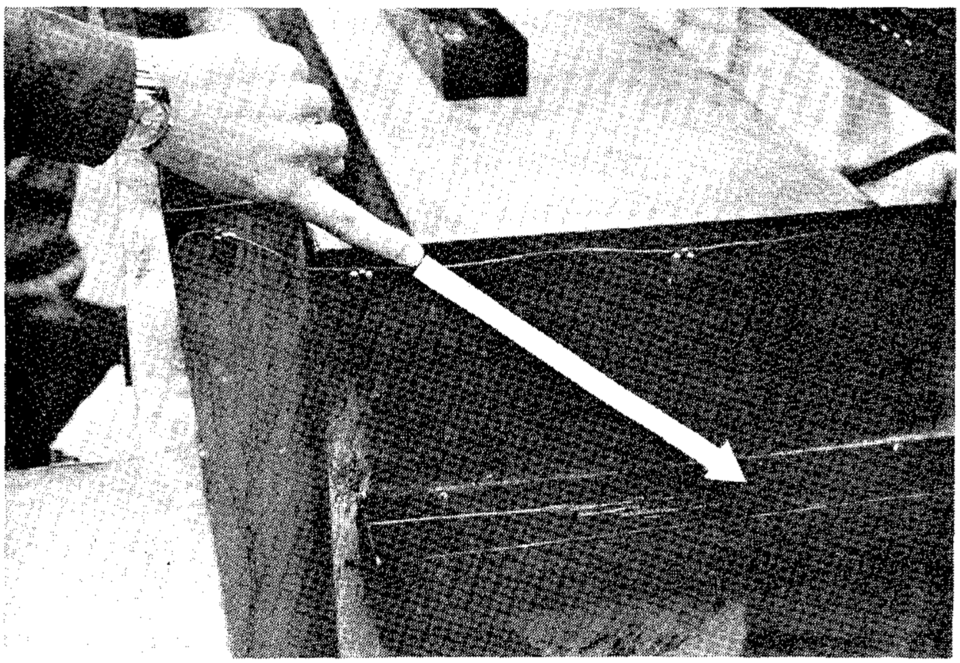
REMOTE MANUAL ACTUATOR AND ELECTRIC
ACTUATION DEVICE MOUNTED ON MOCK-UP

FIGURE 56



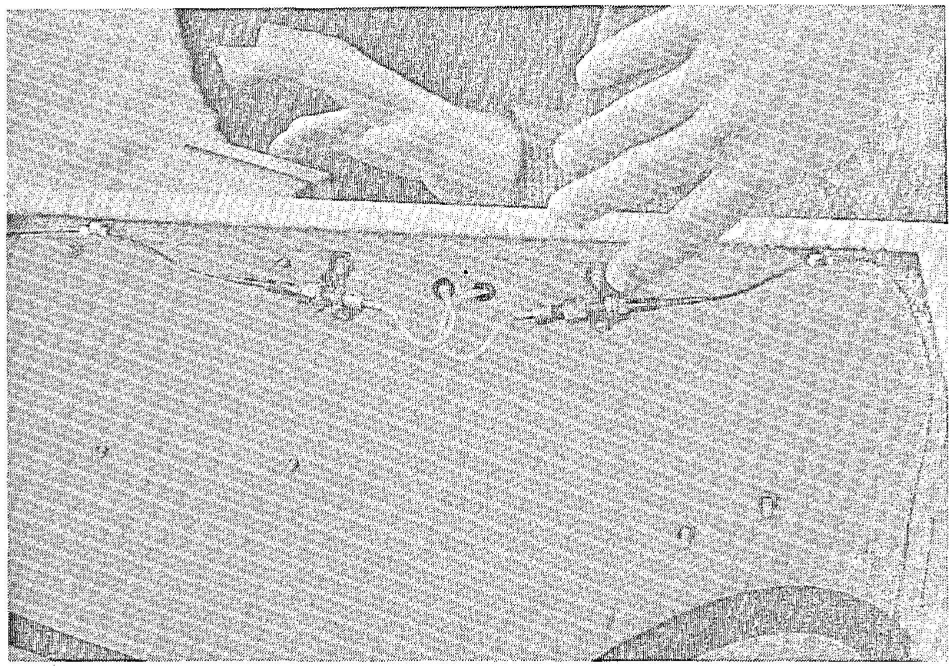
DETECTION WIRE MOUNTED IN ENGINE COMPARTMENT

FIGURE 57



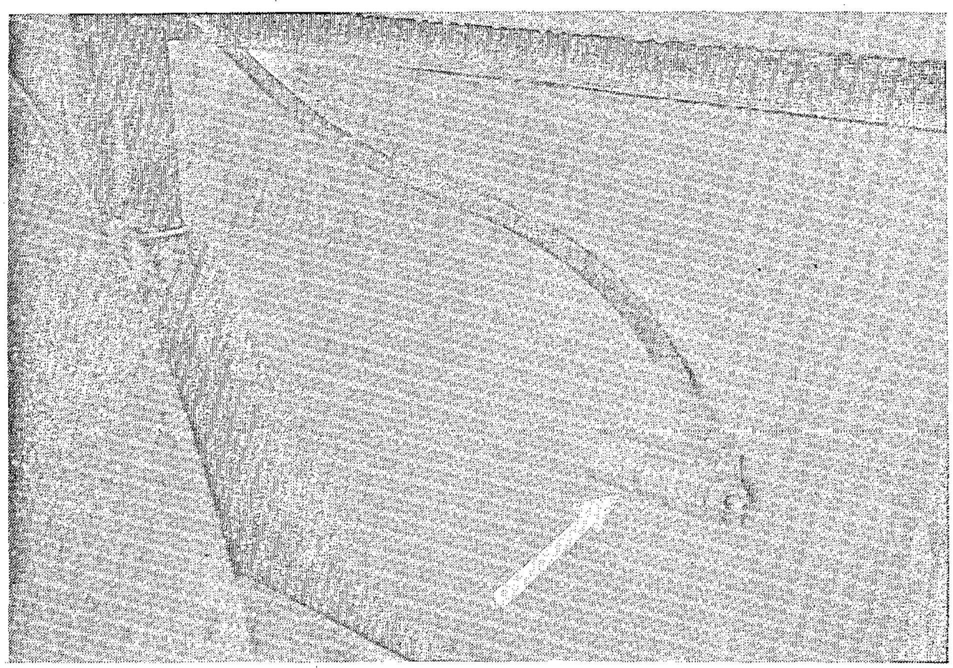
DETECTION WIRE MOUNTED IN TRANSMISSION AREA

FIGURE 58



DETECTION WIRE MOUNTED IN ARTICULATION AREA

FIGURE 59



ENGINE SHUT DOWN DEVICE MOUNTED ON MOCK-UP

FIGURE 60

6.4.2 Nozzle Discharge Testing

The discharge tests on the mock-up were done primarily to determine the discharge characteristics at each nozzle location. Of primary interest were the determinations of (a) the amount of dry chemical that would be discharged from each nozzle, and (b) the spray pattern or extent of coverage that each nozzle would produce. The testing proceeded as follows:

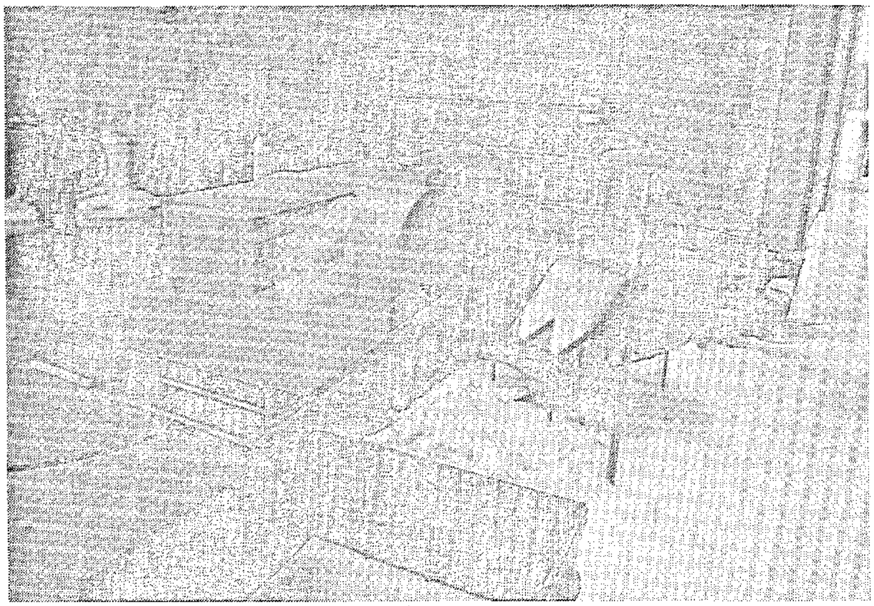
- Weight of Dry Chemical Discharge

  To determine the exact weight of dry chemical that was discharged from each nozzle, a large plastic bag was placed over the nozzle (see Figure 61); the system was then discharged, forcing the dry chemical into the bags (see Figure 62). At the completion of the discharge, each bag was removed from the mock-up and weighed. An average of the discharge weights indicates that the side-mounted engine compartment nozzles discharge approximately 5-1/2 lbs. of dry chemical each, and the remaining four nozzles discharged approximately 3-1/2 lbs. each. This performance is as expected from this distribution circuit design.

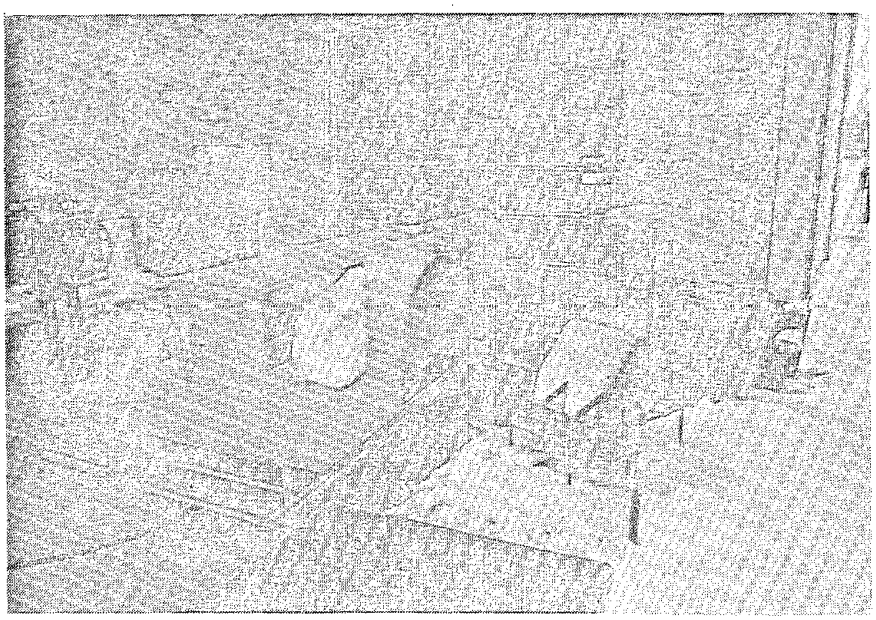
- Extent of Nozzle Coverage

  Although the general spray pattern and extent of hazard protection is well known for each of the two types of nozzles that are used with this system, several discharge tests were run to determine if the coverage was adequate for this particular vehicle. A photographic record was made of each test. It can be seen from Figures 63 and 64 that this system provides more than adequate coverage for the vehicle.

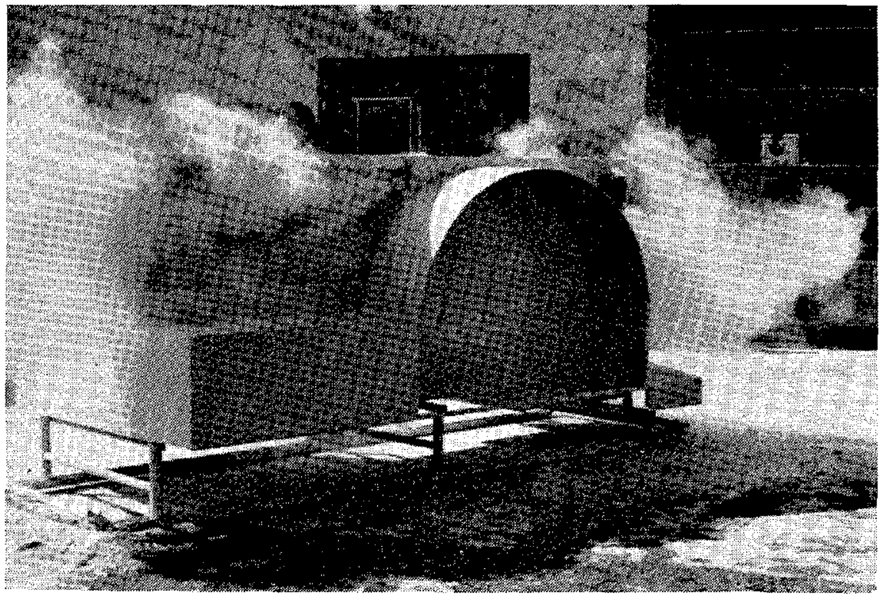
  It should be noted that, as a result of this segment of testing, the nozzle which covers the side of the engine opposite the exhaust manifold was changed



NOZZLE BAGGED DISCHARGE TEST
FIGURE 61

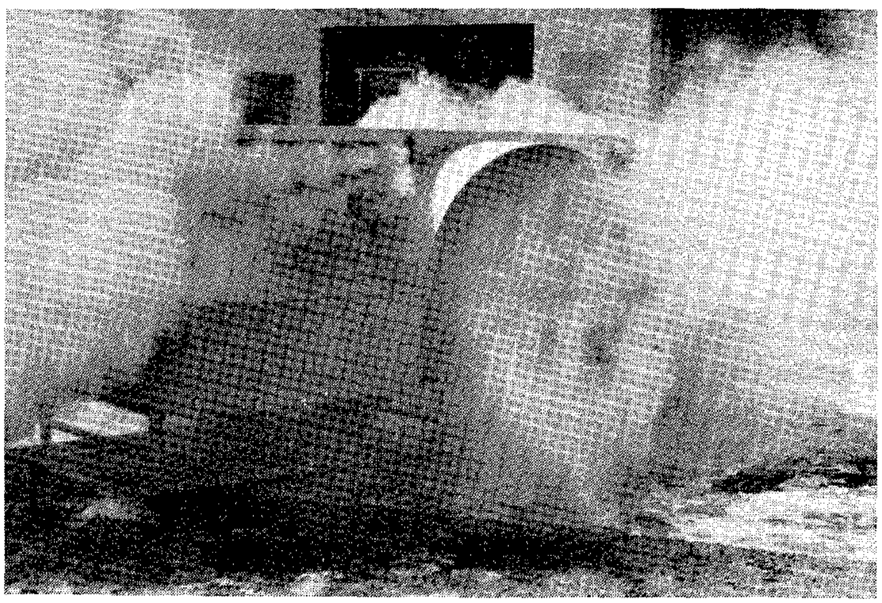


NOZZLE BAGGED DISCHARGE TEST
FIGURE 62



NOZZLE DISCHARGE TESTING

FIGURE 63



NOZZLE DISCHARGE TESTING

FIGURE 64

from a nozzle with a fan-shaped spray pattern to a nozzle with a conical-shaped spray pattern. This change was made in an attempt to achieve greater coverage for that side of the engine.

6.4.3 Preliminary Fire Tests

The purpose of these tests was to determine if the fire control system could extinguish the diesel oil pan fire hazards that were located in various positions on the vehicle. Figures 65, 66, 67 and 68 show the location of the fire pans in the engine compartment (top and right side), engine compartment (left side), transmission compartment, and articulation point respectively.

The testing procedure was as follows. For each test, all of the pan fires were ignited and allowed to preburn for approximately 15 seconds (see Figure 69). The system was then discharged via one of the manual actuation devices. Figure 70 shows the discharge pattern. In all of these tests the pan fires were immediately extinguished upon system discharge.

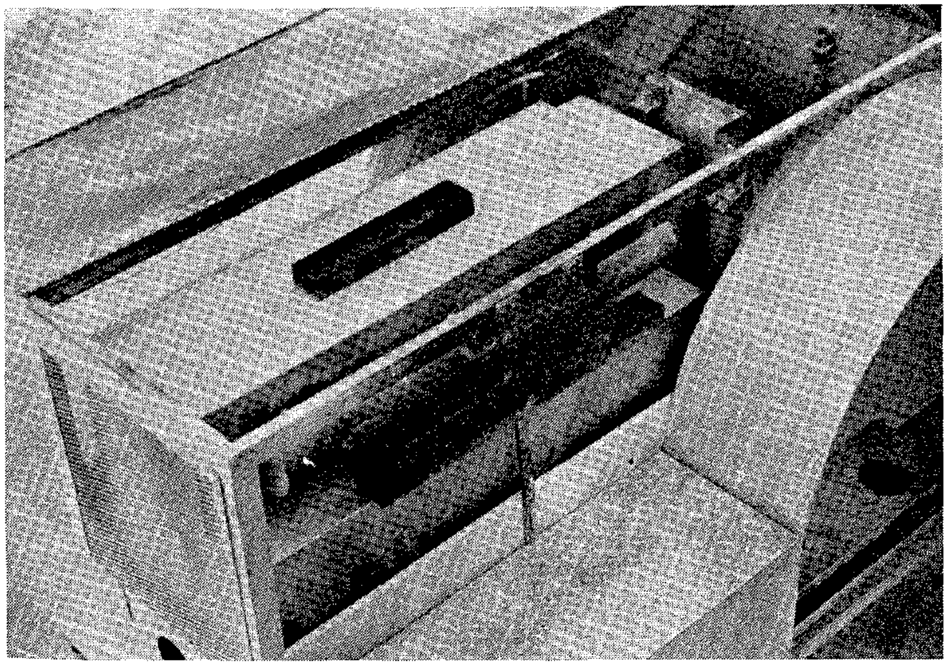
Through repeated testing it was discovered that the fuel oil was being splashed from the pans as a result of the nozzle pressures. To prevent this splashing, a screen mesh material was placed in each pan, and the depth of the fuel oil was not allowed to exceed the height of the screen mesh material. These preventative measures have no adverse effects on the fire extinguishing capabilities of the AFCS.

6.4.4 AFCS Fire Tests on Mock-Up

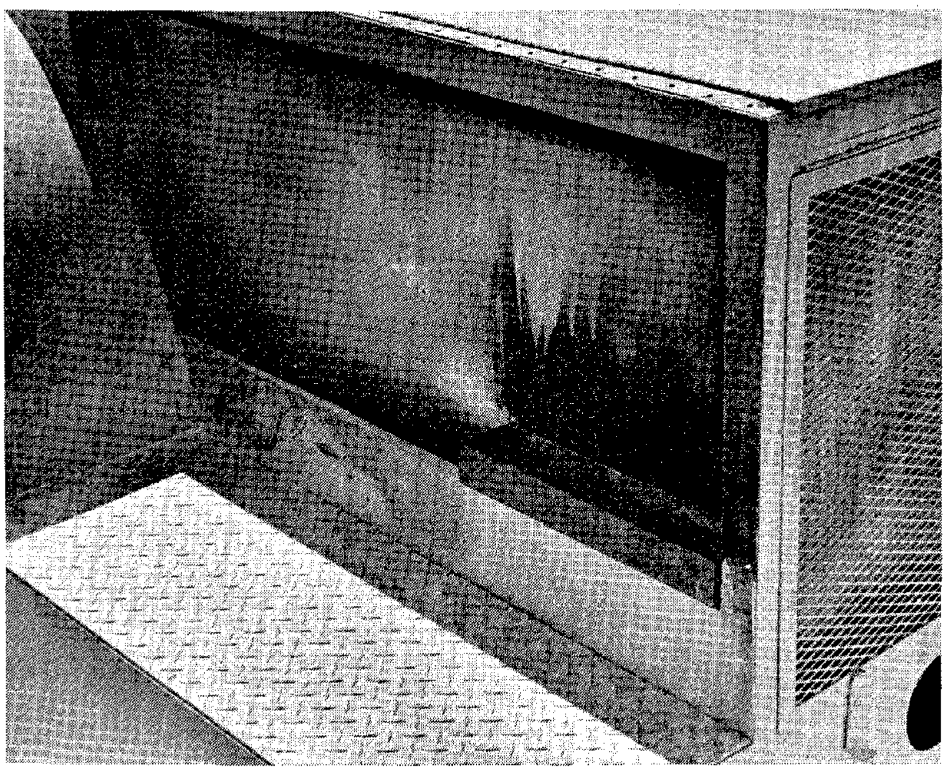
This testing was run in two segments. The first segment involved only the detection system. The second segment involved testing of the entire AFCS. A discussion of the results follows:

- Detection System Testing

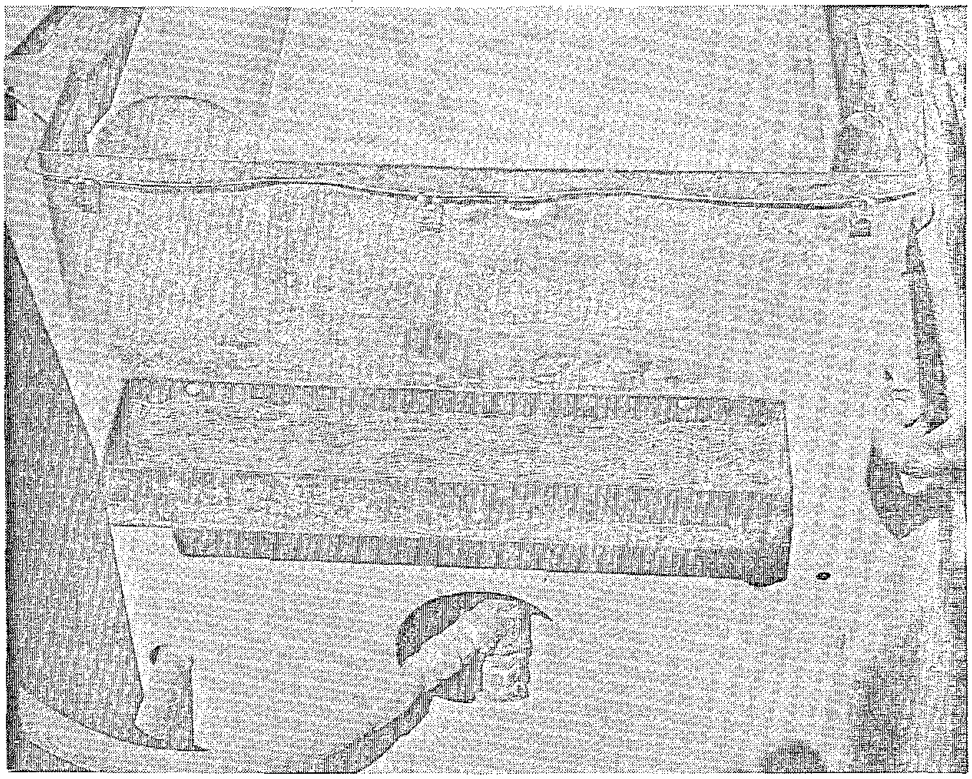
  It was necessary to determine if each individual pan fire would produce a sufficient amount of heat



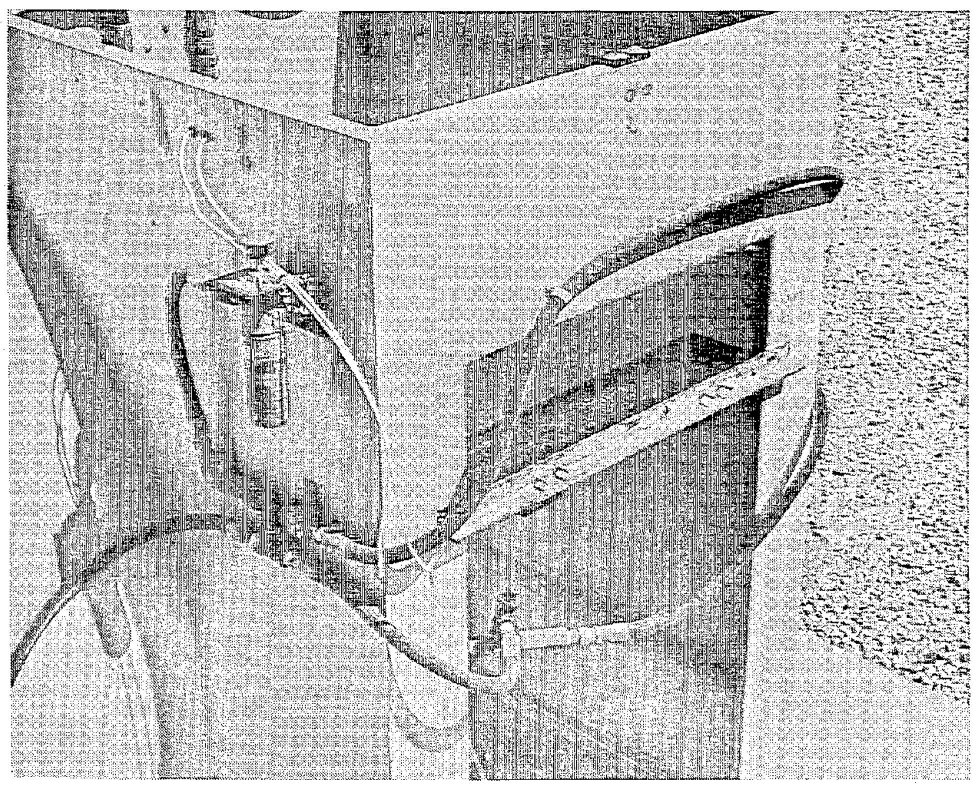
FIRE PAN, ENGINE COMPARTMENT TOP AND LEFT
FIGURE 65



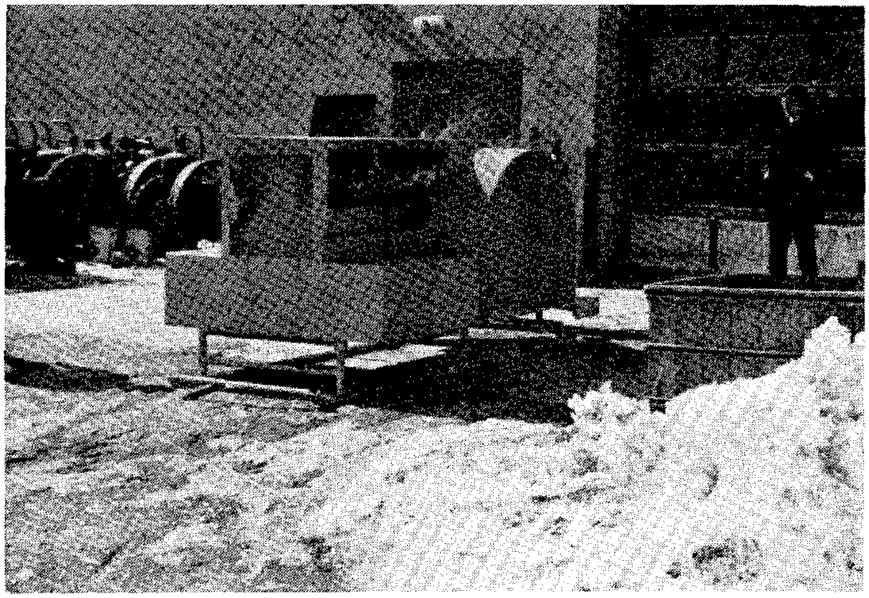
FIRE PAN, ENGINE COMPARTMENT RIGHT SIDE
FIGURE 66



FIRE PAN - TRANSMISSION AREA
FIGURE 67

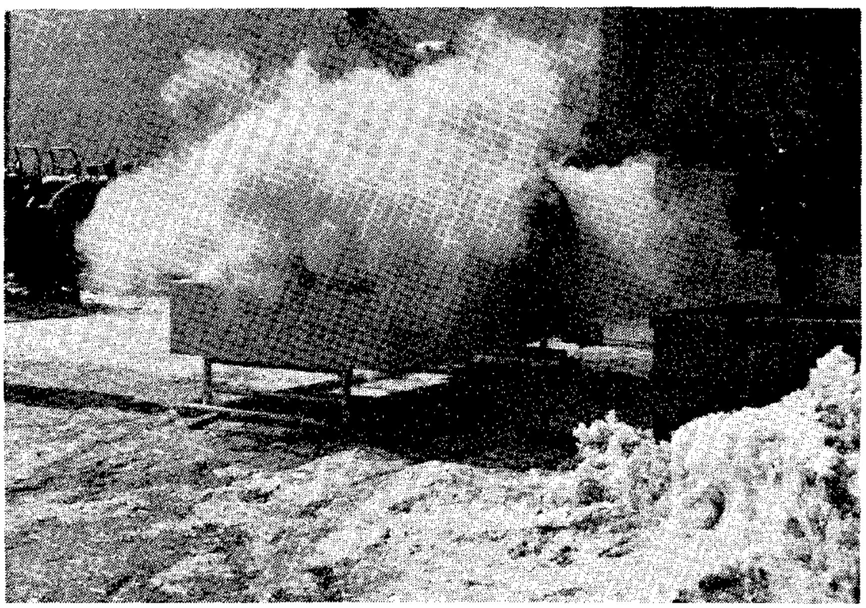


FIRE PAN - ARTICULATION AREA
FIGURE 68



PAN FIRE, PRE-BURN TESTS

FIGURE 69



MANUAL DISCHARGE TEST OF FIRE CONTROL
SYSTEM TO EXTINGUISH PAN FIRES

FIGURE 70

energy within a reasonable amount of time to set off the detection system. Each of the tests were run when the ambient wind conditions were similar (approximately 15 mph) to what might be encountered in a mine. The results of this first segment of testing revealed that each pan fire alone was adequate to set off the detection. However, considerable time was required in the engine compartment and articulation point locations (approximately one to two minutes).

To remedy this situation, the articulation point pan fire was moved from the bottom of the mock-up to a location that was closer to the detection wire, and an additional pan fire was added above the exhaust manifold of the engine. Retesting produced more satisfactory response times.

However, the pan fires still did not simulate what is considered to be the real fire hazard, i.e., spraying fuel from a broken diesel fuel or hydraulic oil line. To simulate this hazard, an empty pressure container was fitted with a 6' long nozzle made of 1/4" copper tubing. The copper tubing was then pinched at the discharge end to achieve an atomized spray mist of fuel. The pressure container itself was partially filled with diesel fuel and pressurized to 300 psi. A spring-loaded shut-off valve was used atop the container to control the flow of fuel from the nozzle. The discharge tip of the 6' long nozzle was positioned where it could spray its fuel directly over the pan fire which is adjacent to the exhaust manifold on the mock-up.

The results were as expected. The burning exhaust manifold pan fire immediately ignited the spray of fuel oil as a hot exhaust manifold would have done in a real situation. The intense fire that was created instantaneously generated sufficient heat to set off the detection circuit and sound the alarm devices on the control console.

A typical engine pan fire is illustrated by Figure 71 and the same fire supplemented by an atomized spray of diesel fuel across the engine is illustrated by Figure 72.

- Fire Tests with Complete AFCS

Since extinguishment of the pan fires alone had already been demonstrated in Section 6.4.3 of the mock-up testing, this fully automatic test sequence was only run with the more difficult atomized fuel spray fire hazard.

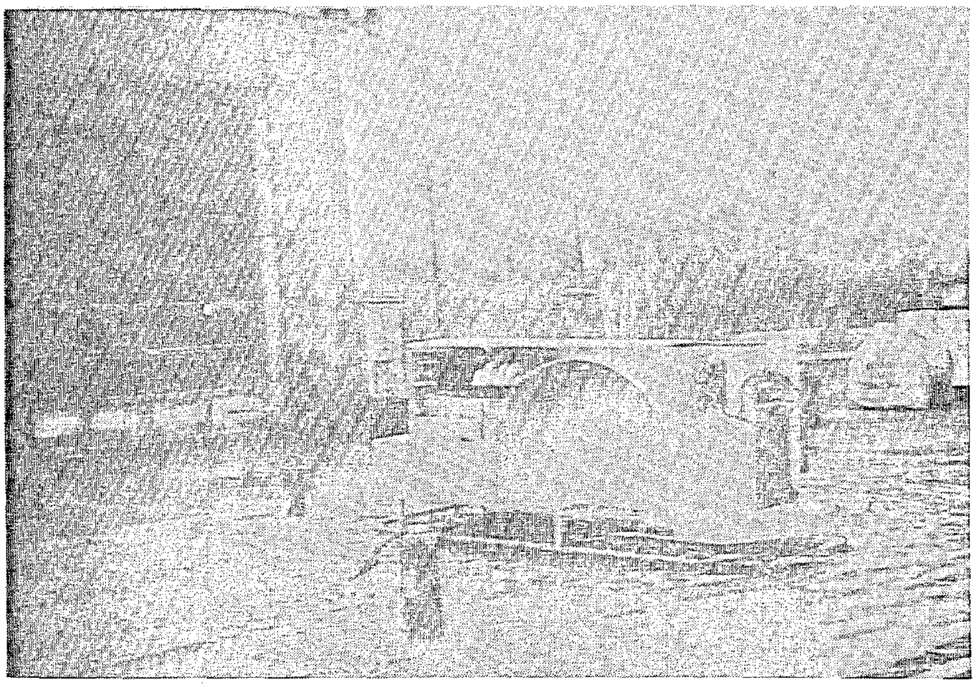
As before, this intense fire was sensed almost immediately after ignition. Upon detection, the control console circuitry energized the electrical actuation device, allowing it to puncture its actuation gas cartridge. This actuation gas then acted to puncture the expellant gas cartridge which, in turn, released the dry chemical agent and brought about the extinguishment of the fire.

The fuel spray was left on for the duration of the dry chemical discharge to ensure that the fire control system could maintain extinguishment throughout the discharge period.

6.4.5 Demonstration Tests for Bureau; AFCS on Mock-Up

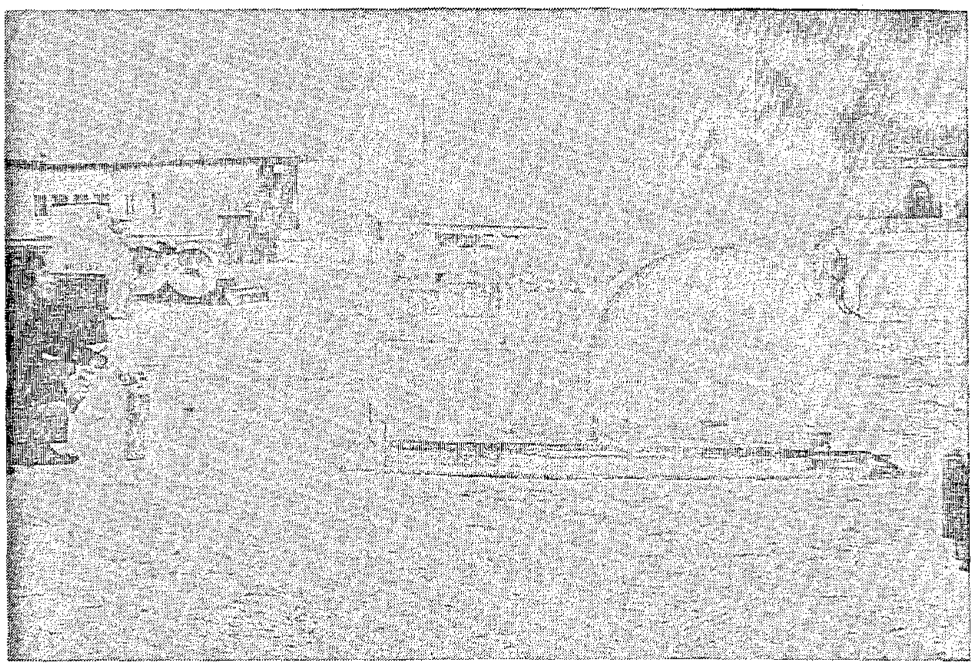
Four separate tests were run on the LHD mock-up. Since testing procedures were identical to those described in Section 6.4.4, only a summary of the results of these additional tests will be offered at this time.

The first test consisted of lighting the articulation point pan fire in an attempt to set off only the detection system. Due to the cold, rainy and windy weather, there was quite a longer than normal delay before the linear thermal sensor reacted to sound the alarm devices on the control console. The problem involved getting the rain-soaked fuel oil to burn properly under the cold ambient temperature conditions.



ENGINE COMPARTMENT PAN FIRE

FIGURE 71



SIMULATED FUEL SPRAY FIRE TEST

FIGURE 72

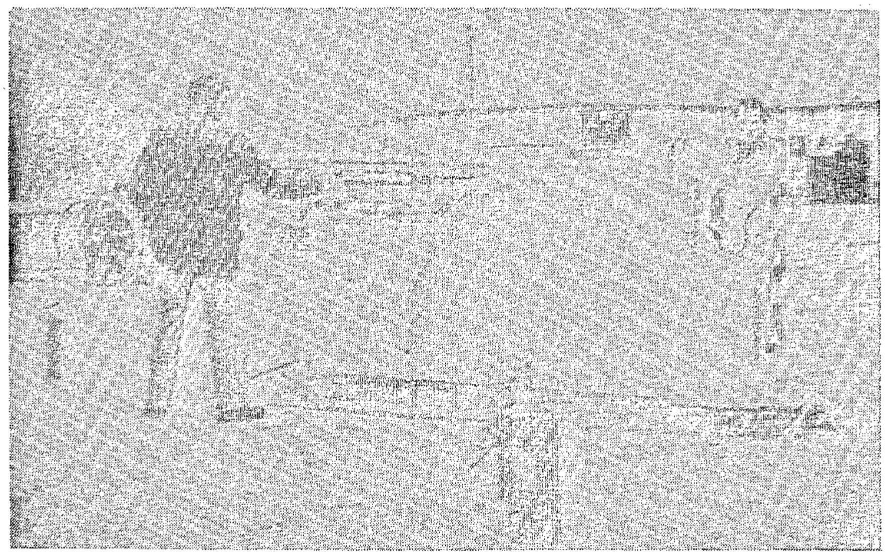
The second and third fire tests involved the transmission and engine compartment (exhaust manifold site) respectively. For each of these tests, the entire AFCS was utilized for the detection, actuation, and extinguishment of the pan fire.

Figures 73 through 77 show the sequence of events from ignition of the pan fire to final extinguishment.

It should be noted that during the third test sequence the snap ring which holds the puncture pin securely in place within the electrical actuation device broke, releasing the pin and rendering the EAD inoperative. Upon examination of this particular prototype unit at a later date, it was discovered that the wrong size puncture pin and snap ring had been used in its construction. This failure, which did not occur until after well over 150 actuations of the device, is to be attributed to this use of incorrect materials, and not to the basic design itself. Also, further prototypes will be assembled with the correct materials, thus avoiding a recurrence of this problem.

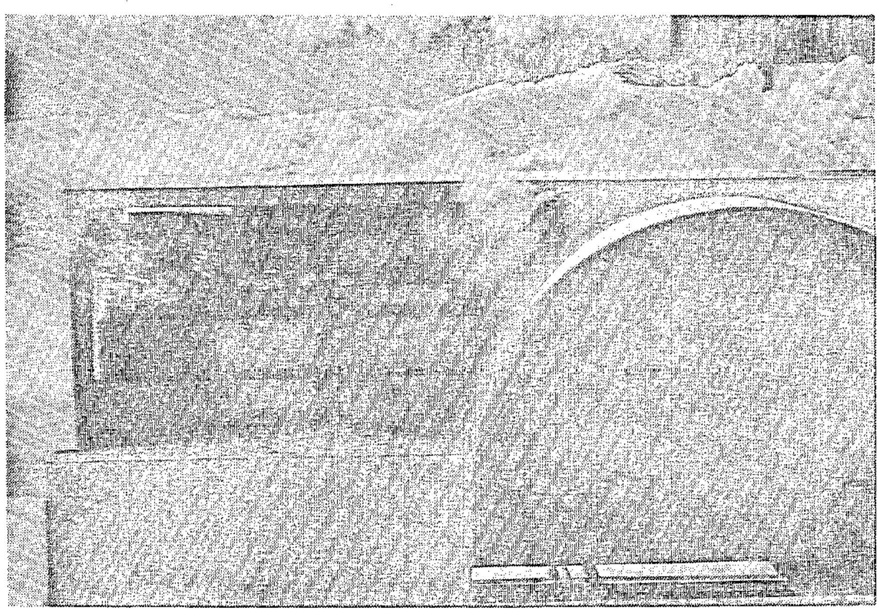
The fourth and final demonstration test involved a repeat of the atomized fuel spray fire (see Figure 72). The system was discharged manually, but the fire signals on the control console actuated almost immediately and the fire was extinguished almost immediately after the start of the dry chemical discharge.

Figure 78 shows personnel of The Ansul Company and the Bureau of Mines inspecting the mock-up after the final test of the demonstration.



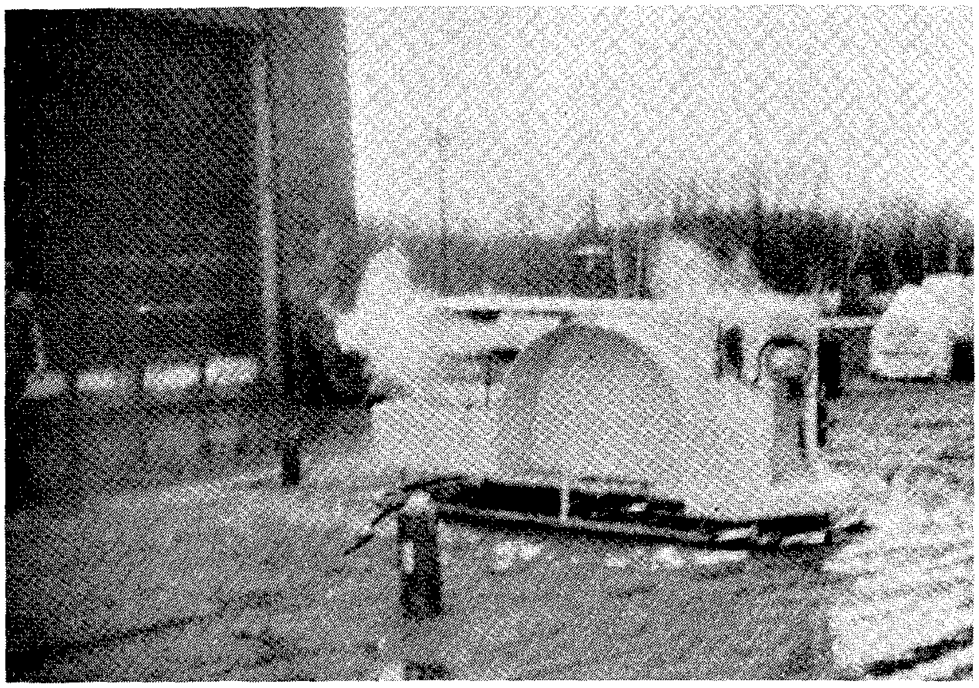
IGNITION OF PAN FIRE IN ENGINE COMPARTMENT

FIGURE 73

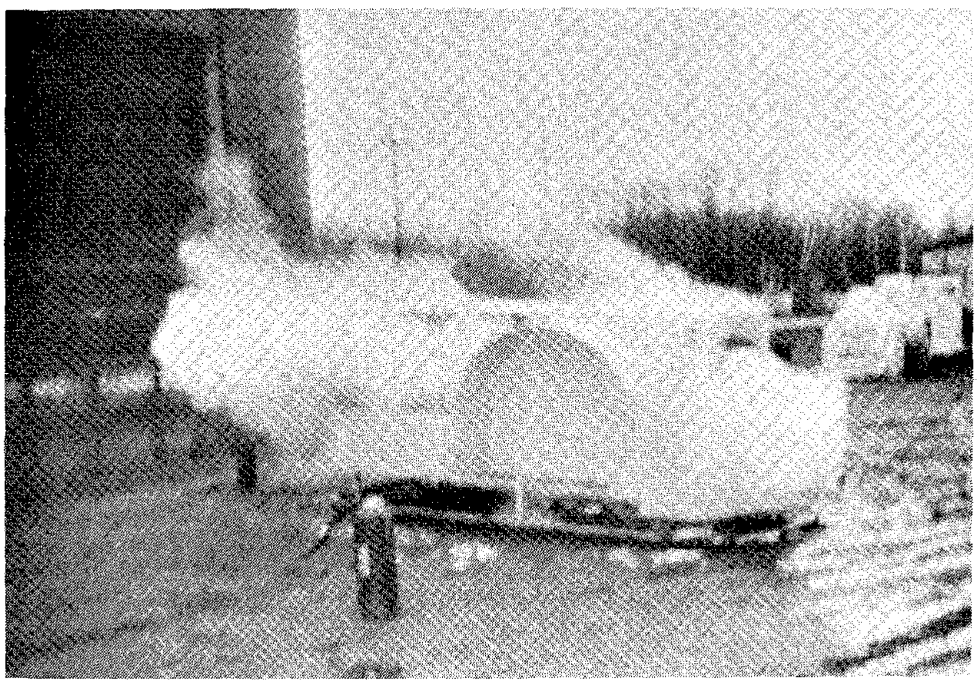


AUTOMATIC SYSTEM DISCHARGE

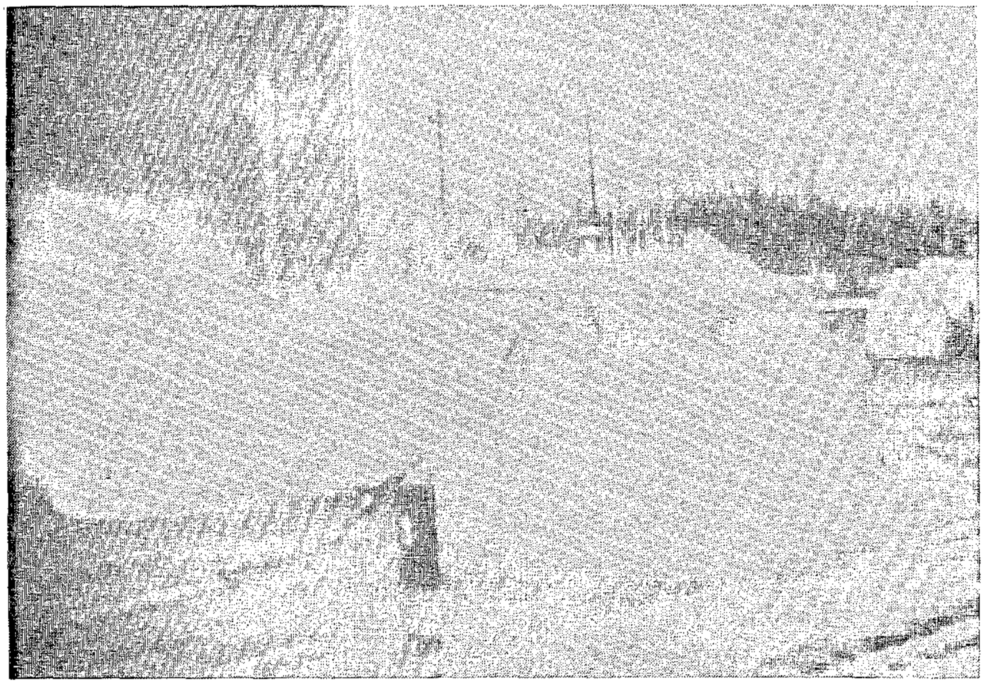
FIGURE 74



AUTOMATIC SYSTEM DISCHARGE
FIGURE 75



AUTOMATIC SYSTEM DISCHARGE
FIGURE 76



AUTOMATIC SYSTEM DISCHARGE

FIGURE 77

ANSUL AND BUREAU OF MINES PERSONNEL INSPECTING MOCK-UP

FIGURE 78

7.0 FIELD DEMONSTRATION

7.1 Planning for Field Demonstration

The field demonstration involved underground fire tests demonstrating the performance of an automatic fire control system (AFCS) installed on a load-haul-dump (LHD) vehicle. The selection of the LHD vehicle class for the test was made in Phase II of the contract (reference Section 4.1).

The Ansul Company and the Hecla Mining Company began planning early in December 1975 towards a cooperative effort to perform the required field demonstration. An agreement between the two companies (see Appendix D-1) determined that the field demonstration would be performed at the Lakeshore Project of the Hecla Mining Company, Casa Grande, Arizona. The LHD vehicle selected for the test was a Wagner ST-2B-LHD. It was established that the demonstration would occur in the East Exhaust Drift at the 500 Level (approximately 1400 feet below the surface).

Since the Federal Standard 57.4-58 prohibits the lighting of fires underground, it was necessary to obtain a variance to the Federal Standard in order to perform the field demonstation. The application for a variance was initiated by the March 18, 1976 letter from The Ansul Company to Mr. Robert E. Barrett, MESA Administrator (see Appendix D-2). The MESA letter to Ansul of April 1, 1976 (see Appendix D-3) advised that the variance request was being processed. Since Arizona is a State Plan state, the variance was issued by the office of the Arizona State Mine Inspector with the concurrence and approval of MESA. The variance (see Appendix D-4) dated April 15, 1976 was received prior to the demonstration. The Hecla Mining Company employees were advised of the test plans by the Hecla memorandum dated May 10, 1976 (see Appendix D-5) and each employee was required to acknowledge reading the memorandum.

The field demonstration was witnessed by representatives of the Bureau of Mines Twin Cities Mining Research Center,

MESA Phoenix Office, Arizona State Inspector's Office, and participating representatives of the Hecla Mining Company and The Ansul Company. Each of the witnesses attended a pre-test briefing in which the detailed test plans were presented (see Appendix D-6) and the safety procedures and plans were reviewed by Mr. Claude Huber of the Hecla Mining Company.

7.2 AFCS Installation on LHD

The automatic fire control system (AFCS) was installed on a Wagner ST-2B-LHD while underground at the Lakeshore Project of the Hecla Mining Company during the period May 7-9, 1976 (reference Figure 79). The test vehicle is an LHD-Wrecker, i.e., the vehicle has a hydraulically operated arm and towing device behind the articulation section instead of the standard shovel.

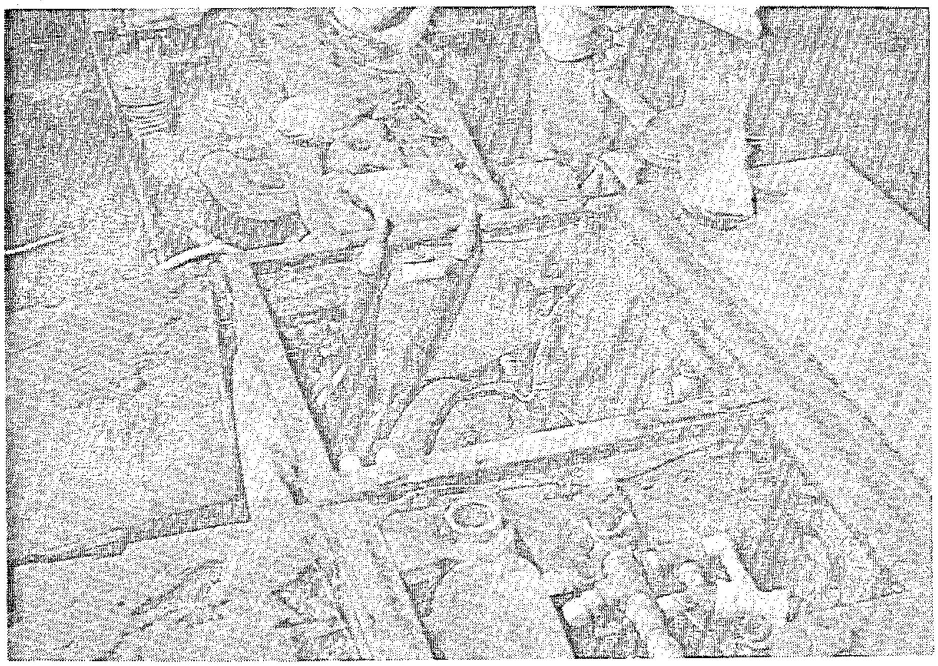
The system design and installation were in accordance with the development effort of the previous phases of the contract. The installed system provides fire protection for the engine area, the transmission area, and the articulation area. The system concept includes a continuous strip thermistor wire detection system with a control console which senses the detection wire, actuates the suppression system on command from the detection system, supervises the detection circuit for malfunctions, and includes visual and audible alarms. The fire suppression system is a fixed pipe dry chemical system with an electric actuation device actuated on command from the control console. The AFCS also includes two manual actuation devices which can override the automatic system and accessories which shut down the engine and apply the vehicle brakes when the AFCS is actuated. The system schematics, which appear in Section 6.1.1, continue to describe the system.

The identity and location of the AFCS components is described in the following discussion. The function of each component is explained in more detail in Section 6.2.

The detection wire is a continuous circuit starting at the control console, then looping the articulation area, the transmission area, and with loops above and in the belly pan of the engine area. Figure 80 illustrates the detection

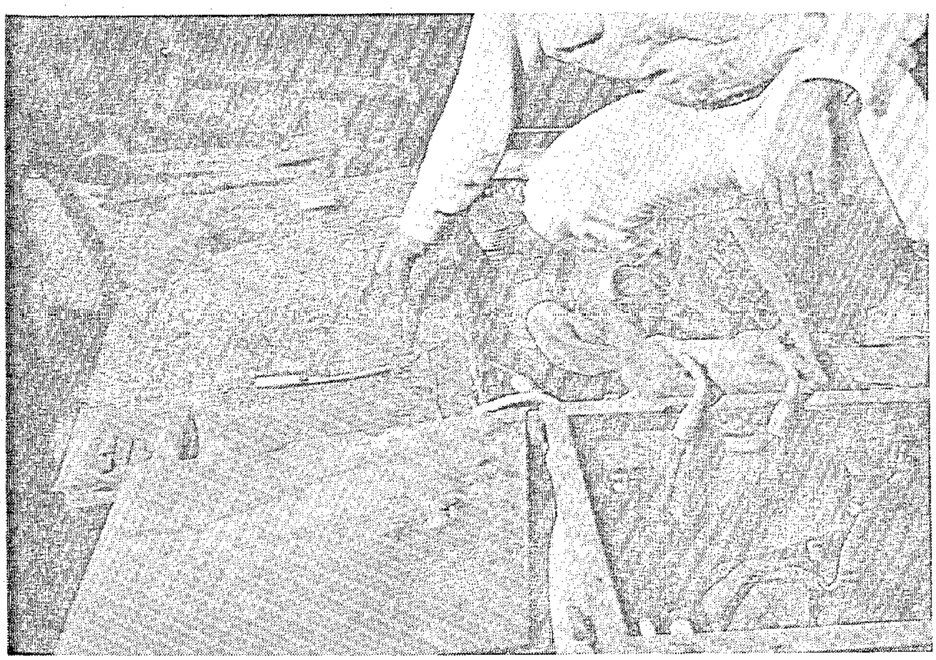
ENTRANCE TO HECLA LAKESHORE PROJECT

FIGURE 79



DETECTION WIRE IN TRANSMISSION AND ARTICULATION AREAS

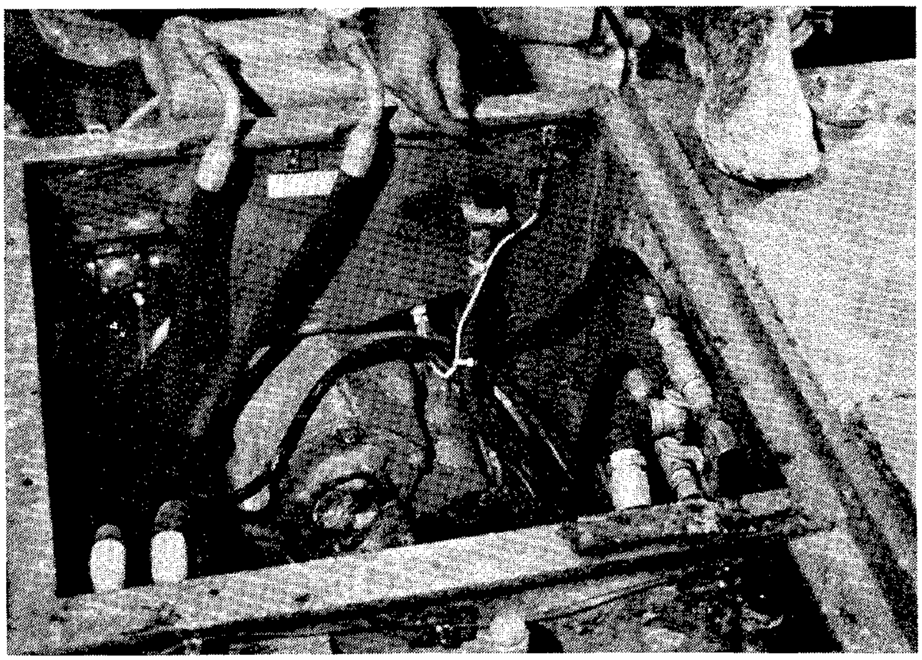
FIGURE 80



DETECTION WIRE ON ENGINE COVER

FIGURE 81

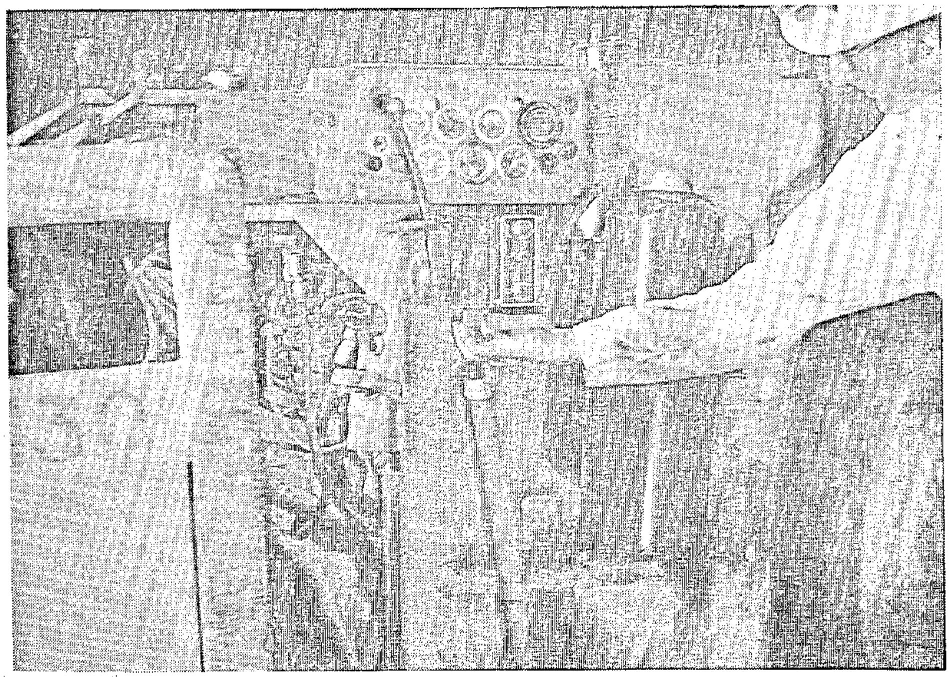
wire installation in the articulation and transmission areas and Figure 82 illustrates the installation on the engine cover above the engine. The belly pan loop is hidden from the view of the camera. Fire zone wire is used to couple sections of the detection wire and complete the circuit. Figure 82 illustrates a section of the fire zone wire running towards the belly pan loop from the top of the transmission area.



FIRE ZONE WIRE IN TRANSMISSION AREA

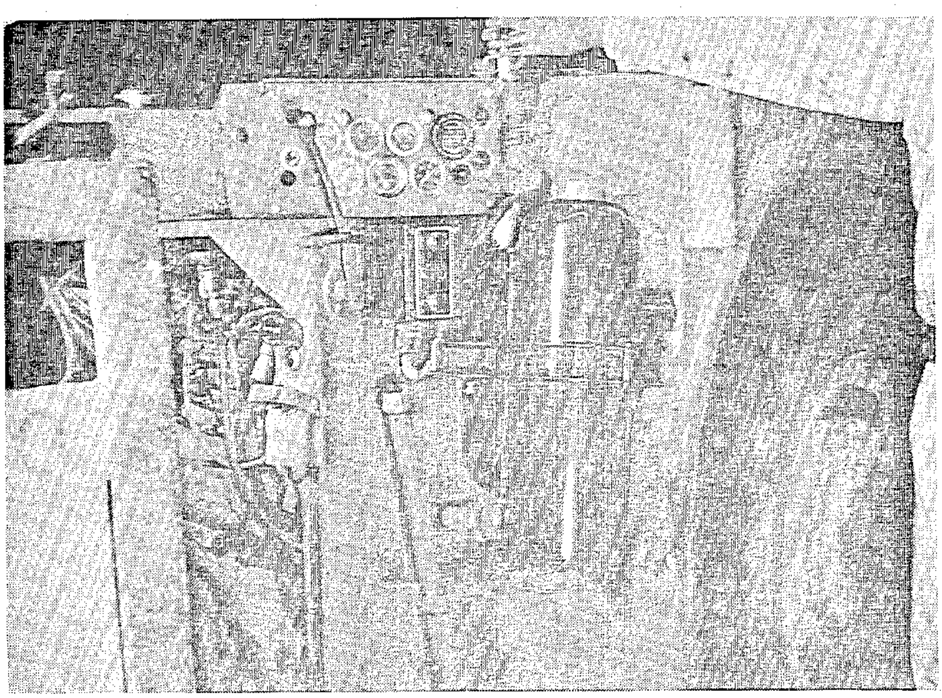
FIGURE 82

Several of the components are mounted near the vehicle operator's dashboard as shown in Figures 83 and 84. The hand shown in Figure 83 is operating the test switch on the control console which tells the operator that the warning lights and audible alarm are functional. The hand shown in Figure 84 demonstrates the vehicle operator pushing the "Fire" button on the dashboard actuator. In this same area, the dry chemical agent container is shown bolted to the wheel fender using the new heavy-duty mounting bracket which has been designed to withstand the severe environment on vehicles of this type.



DASHBOARD AREA - INDICATING TEST SWITCH AT CONTROL CONSOLE

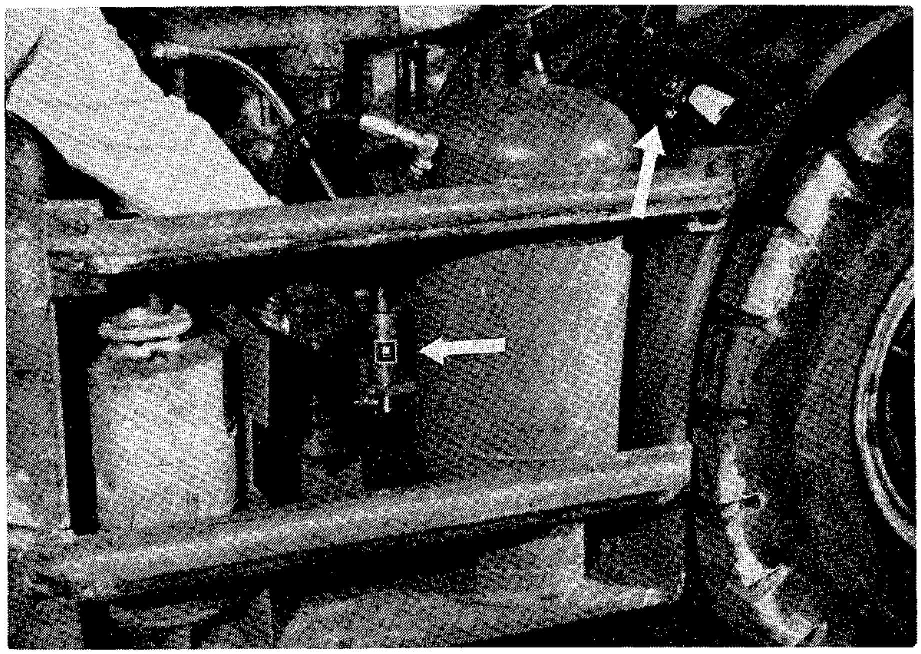
FIGURE 83



DASHBOARD AREA - INDICATING DASHBOARD ACTUATOR

FIGURE 84

The other two system actuation devices are mounted on the opposite side of the vehicle from the operator. Figure 85 shows the remote manual actuator on the wheel fender, and the automatic electric actuation device mounted in the lower left side of the engine area.

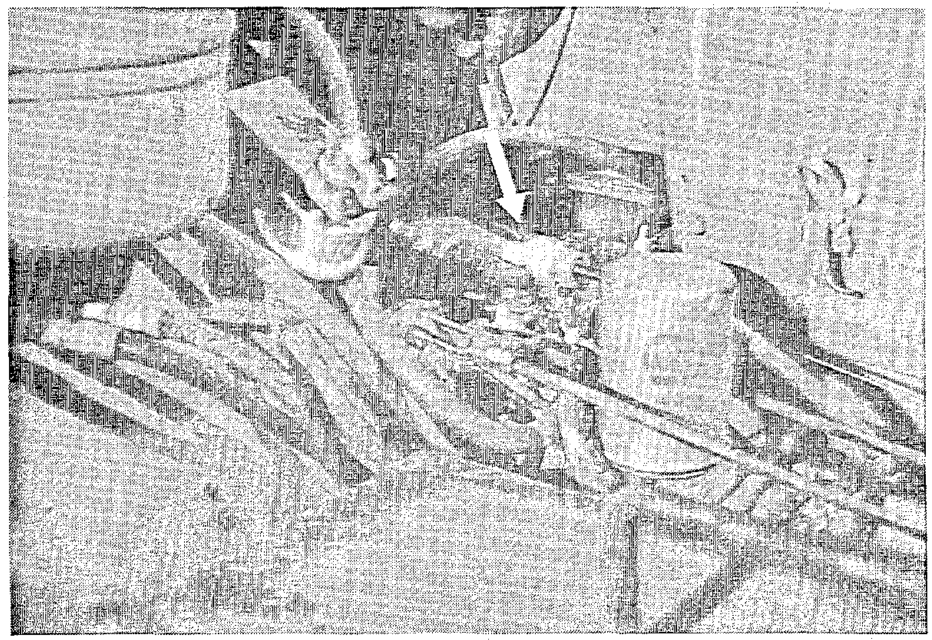


LEFT SIDE OF ENGINE AREA
ELECTRIC ACTUATION DEVICE AND REMOTE ACTUATOR

FIGURE 85

There are two accessories which are part of the actuation system. The engine shut-off air cylinder is shown in Figure 86 at the rear, right, lower part of the engine area. The other accessory is the pilot-operated valve which sets the vehicle brakes when the AFCS is actuated. This valve is located under the dashboard behind the panel and cannot be photographed.

When the system is actuated, the fluidized dry chemical is distributed to six nozzle locations through hydraulic hose lines. Figure 87 illustrates the "triple tee" which is the main distribution point separating the powder flow, and also shows the nozzles flooding the articulation and transmission areas. Figure 88 is a top view of the vehicle with

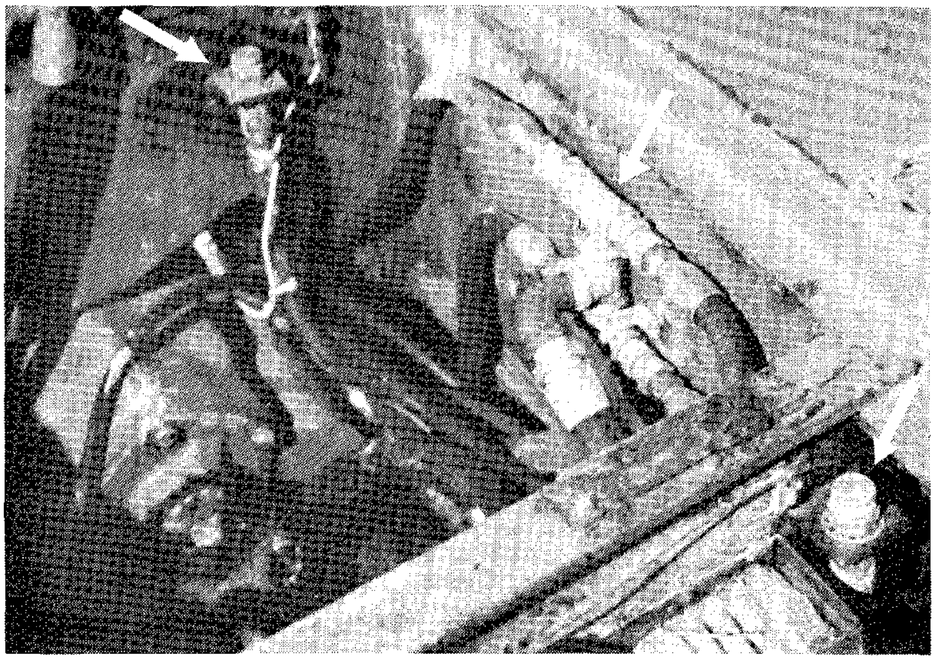


RIGHT SIDE OF ENGINE
AIR CYLINDER (ENGINE SHUT-OFF)
FIGURE 86

the covers open, showing the three areas protected by the AFCS. Figure 89 shows the fan nozzle sweeping the top of the engine area and the conical nozzle which sweeps the right side of the engine. Figure 90 shows the conical nozzle sweeping the left side of the engine. The belly pan nozzle is at the back of the belly pan area within the closed space at the bottom of the engine and cannot be photographed.

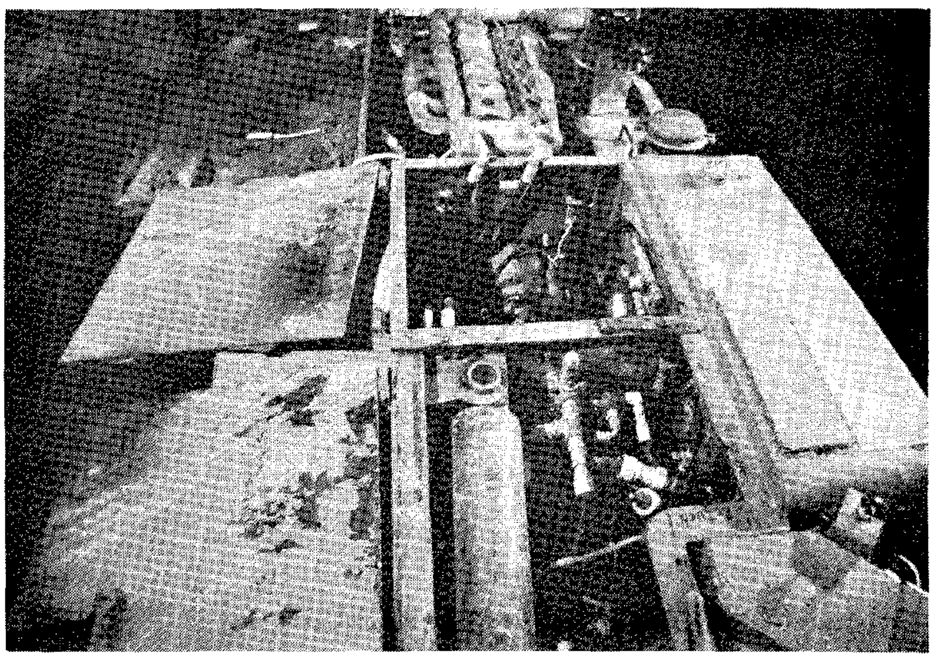
7.3 Field Demonstration

The field demonstration was performed at the Lakeshore Project of the Hecla Mining Company, Casa Grande, Arizona. System discharges and fire tests were performed demonstrating the performance of the automatic fire control system (AFCS) installed on the ST-2B-LHD vehicle. All tests were conducted in the 500 Level, East Exhaust Drift, which is the main exhaust drift for the 500 Level. The drift is 500' long and the tests were performed approximately 200' into the drift. At the exhaust end of the drift, 300' from the test area, the main exhaust vent carries the air directly to the surface. The drift slopes away from the exhaust vent. The cross-section of the draft in the test



TRIPLE TEE DISTRIBUTION FITTING IN TRANSMISSION AREA

FIGURE 87

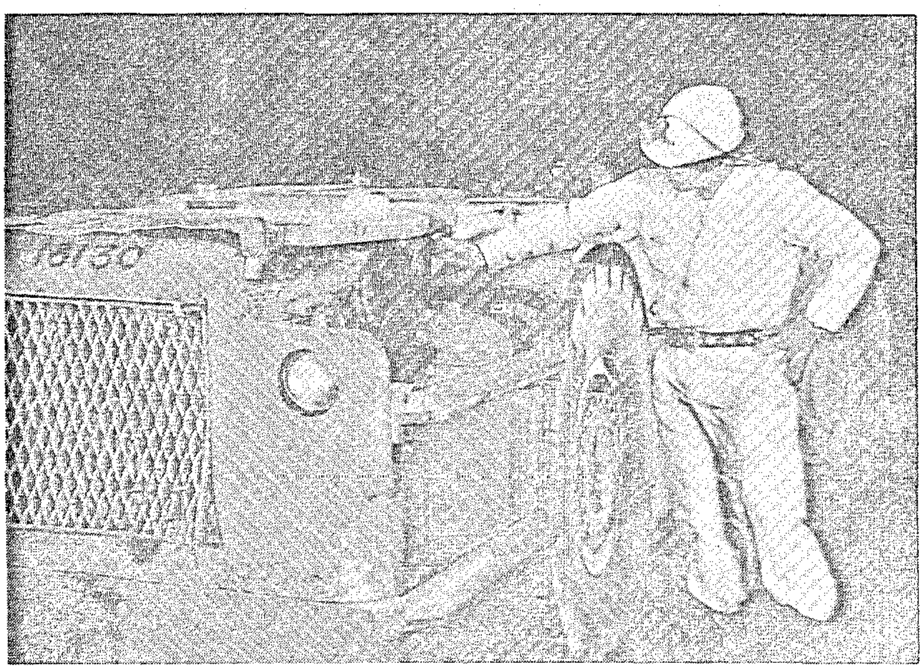


TOP VIEW - PROTECTED VEHICLE COMPARTMENTS

FIGURE 88

ENGINE AREA - NOZZLES SWEEPING TOP AND RIGHT SIDE

FIGURE 89



ENGINE AREA - NOZZLE SWEEPING LEFT SIDE

FIGURE 90

area is approximately 14' x 14'. The normal ventilation rate in the drift was 1700 fpm (19.3 mph). However, during the fire tests the ventilation rate was reduced to 300 fpm (3.4 mph).

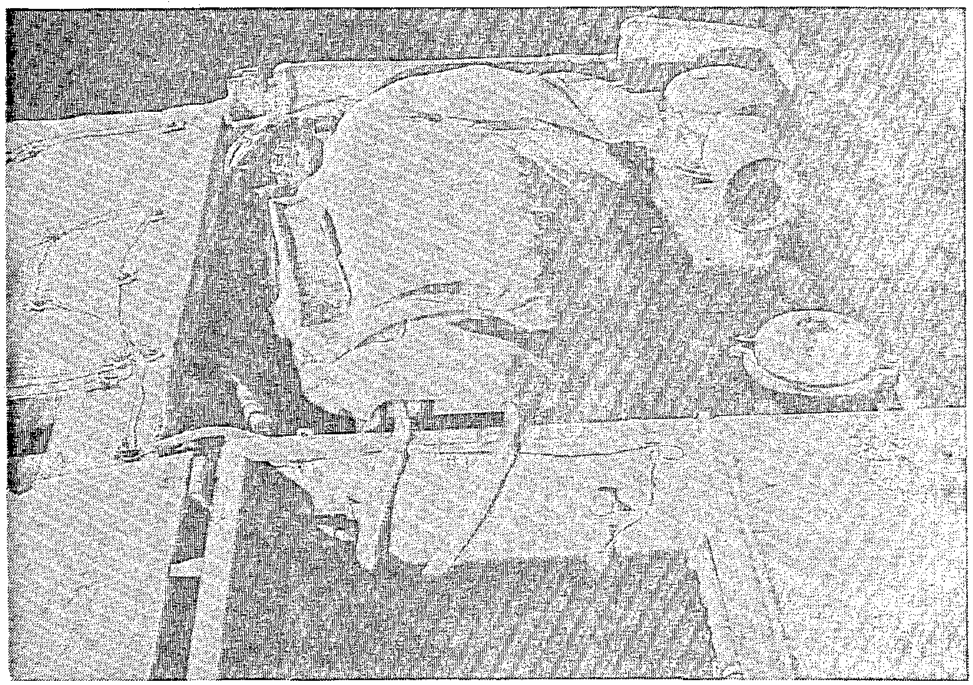
7.3.1 Underground Discharge Tests

Prior to conducting fire tests, the discharge characteristics of the AFCS were demonstrated in the underground test area. These tests were performed on May 12, 1976, one day prior to the fire test demonstration.

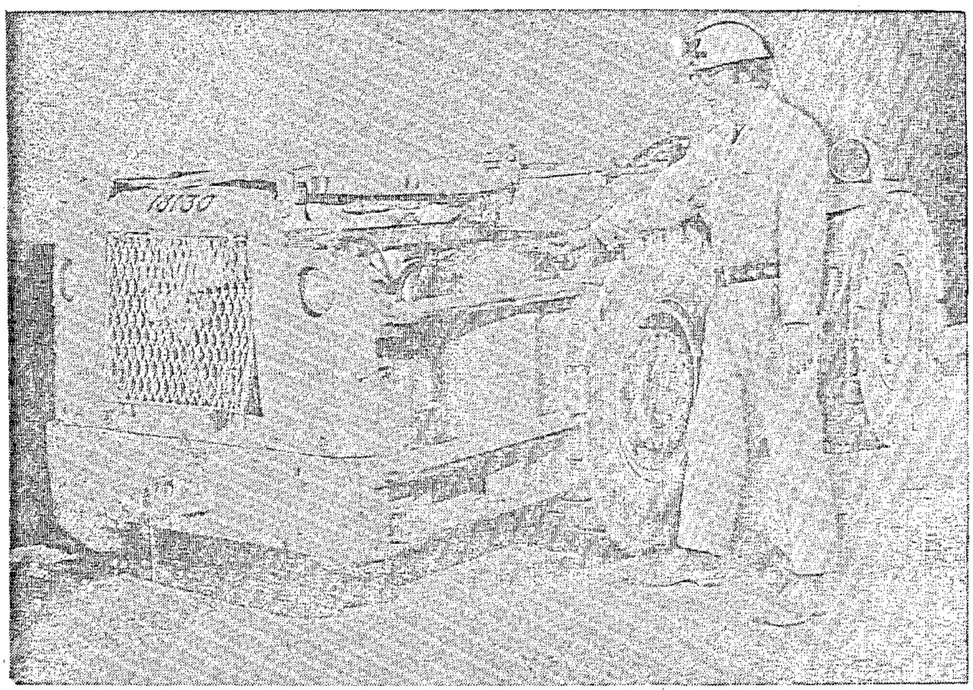
The vehicle was moved into the test area and placed with the engine end of the vehicle facing into the ventilation flow. Asbestos cloth was placed around some of the engine components (such as the generator) to minimize the exposure to the dry chemical agent during the tests. Figure 91 illustrates the placement of the asbestos cloth in the engine area. The addition of the asbestos cloth was the only modification to the vehicle.

Two manual discharge tests of the dry chemical agent were performed. These were the initial functional tests of the full AFCS installed on the LHD. The tests demonstrated: (1) that each of the system components was properly installed and performing its function; (2) the discharge time of the dry chemical agent; and (3) the pattern of the dry chemical discharge.

For the initial discharge test the ventilation flow rate in the drift was reduced to 300 fpm (3.4 mph). The AFCS was actuated by the remote manual actuator as illustrated in Figure 92. The discharge pattern is illustrated by Figure 93. The dry chemical flooded the engine area up to the front air screen, and fully flooded the transmission and articulation areas which are also protected by the system. After the discharge the vehicle inspection confirmed that a uniform dry chemical layer had been deposited through all the protected areas. The discharge time was 10.5 seconds from the time of actuation to the gas point of the dry chemical discharge.



PLACEMENT OF ASBESTOS CLOTH ON ENGINE COMPONENTS
FIGURE 91



REMOTE MANUAL ACTUATION
FIGURE 92

For the second discharge test the ventilation rate in the drift was returned to the normal (for that area) rate of 1700 fpm (19.3 mph), measured. The AFCS was actuated by the dashboard manual actuator. The system discharge pattern is illustrated by Figure 94. The dry chemical penetrated the high air velocity to the front wind screen of the engine, and the dry chemical pattern observed on the vehicle after the discharge was good (Figure 95). The effect of the high air velocity can be seen in the way the powder is turned back into the air flow at the front of the engine when comparing Figures 93 and 94. The 19.3 mph air flow is an extremely high flow for mine operation and the test demonstrates a good discharge pattern under worst conditions. The discharge time was 10.5 seconds.

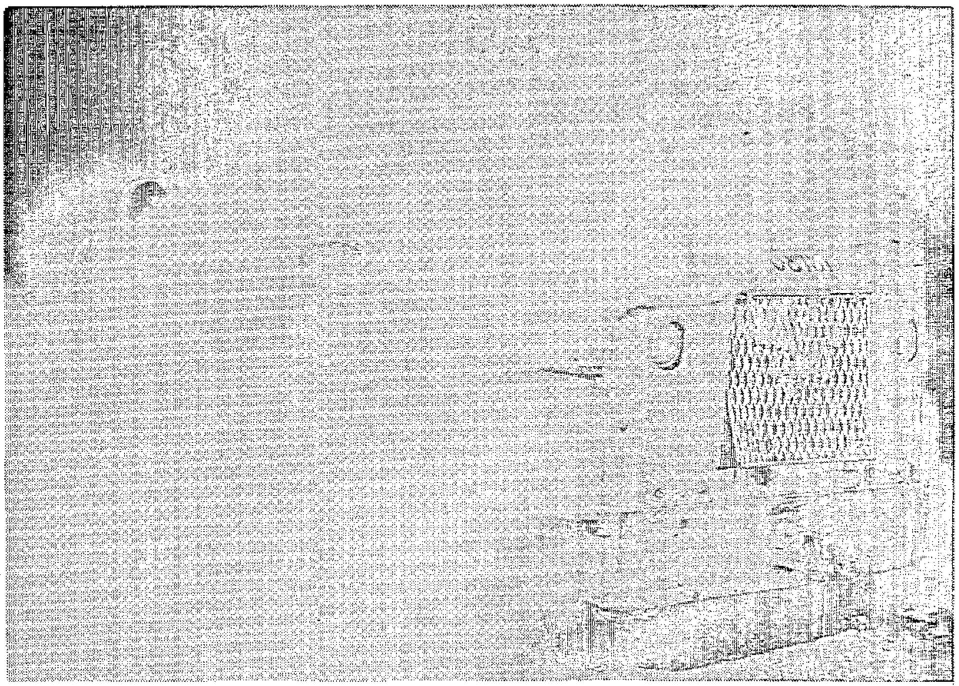
In addition to the two discharge tests, several component functions were checked separately before the fire tests:

- A flame was held under a section of the detection wire; and the functioning of the fire warning light and the audible alarm at the control console, plus the release of the electric actuation device indicated that the detection and control systems were functioning. The pressure cartridges were removed prior to this test.

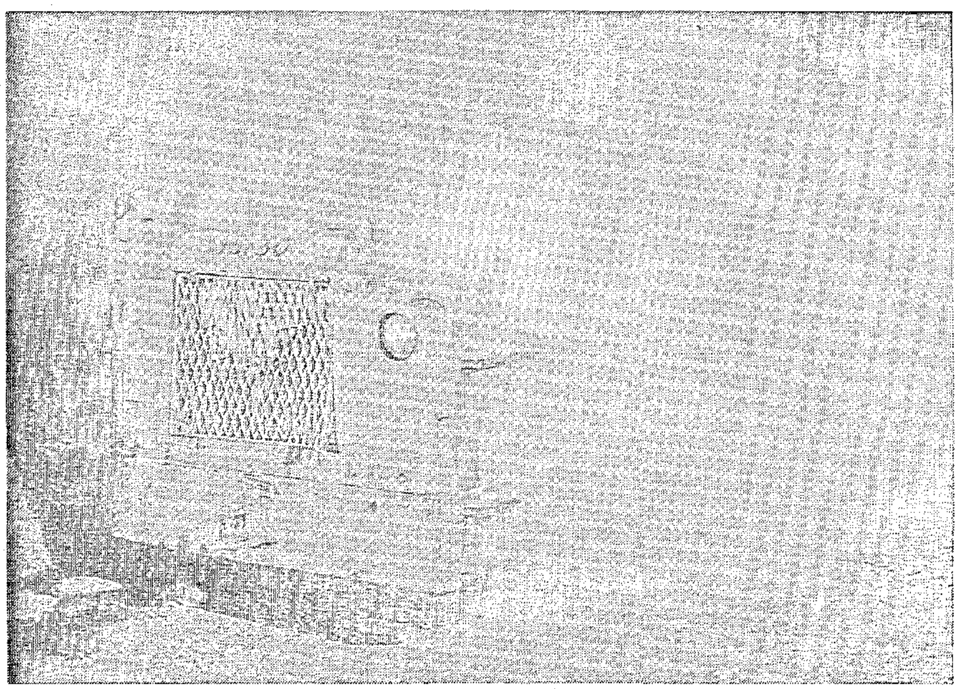
- The actuation system was operated to check the function of the air cylinder. It was observed that the piston in the air cylinder moved its full stroke and closed the diesel fuel control rocker arm, shutting down the engine.

- The function of the brake control valve was also observed when the actuation system was operated. The actuation pressure to the pilot port of the three-way valve caused the valve to close, shutting off the pneumatic pressure to the brake system and bleeding the pressure out of the line between the valve and brake system. The removal of pressure from the brake system caused the brakes to function.

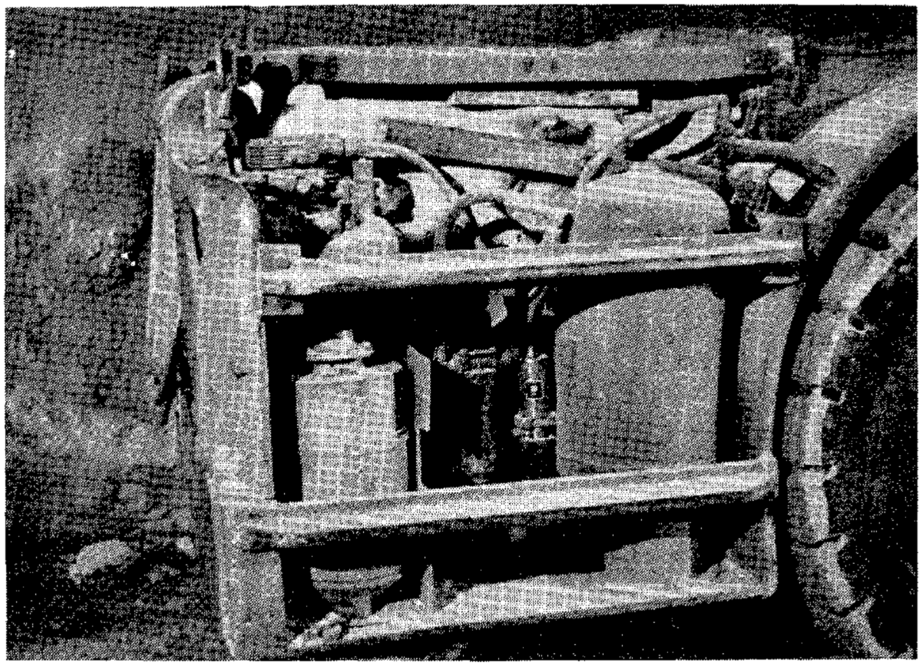
After completing the discharge tests the dry chemical was flushed off the vehicle and the vehicle was put back in service.



DRY CHEMICAL DISCHARGE - 3.4 MPH
FIGURE 93



DRY CHEMICAL DISCHARGE - 19.3 MPH
FIGURE 94

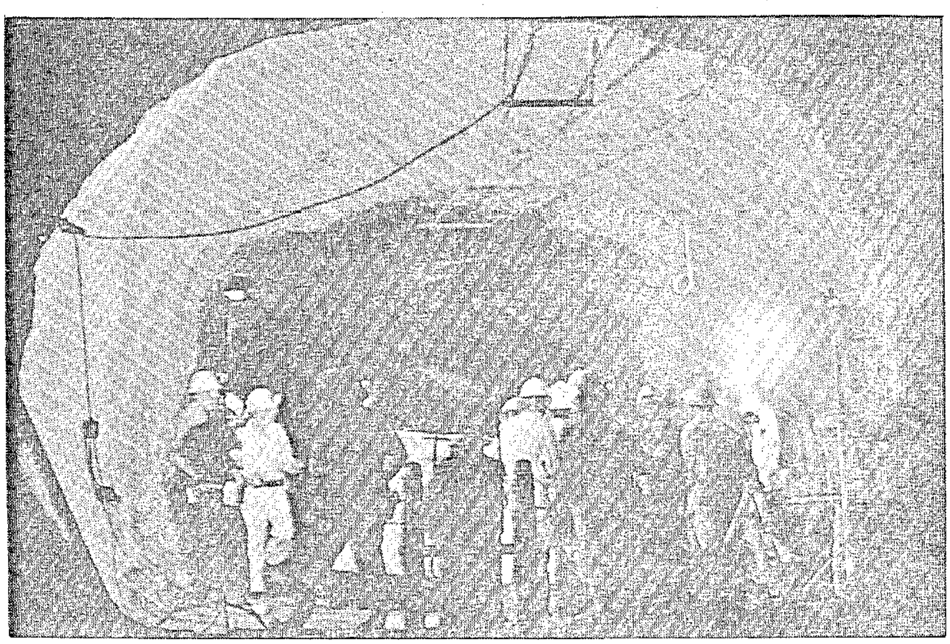


DRY CHEMICAL DEPOSIT ON VEHICLE AFTER DISCHARGE

FIGURE 95

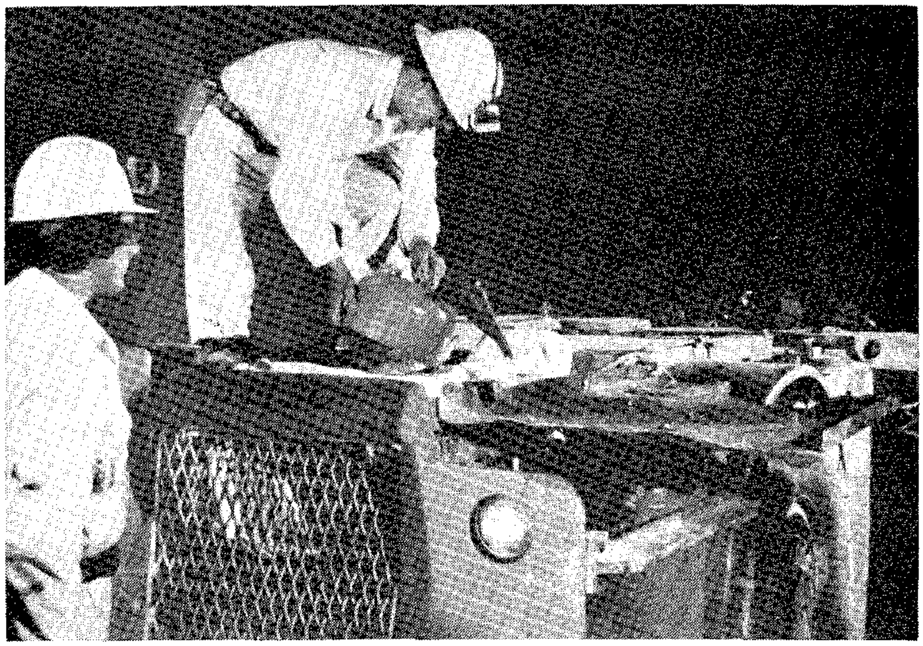
7.3.2 Underground Fire Tests

The underground fire tests were performed on May 13, 1976. The LHD vehicle was driven into the test area at approximately 1:30 p.m. for final preparation (see Figure 96). Critical engine parts were again protected with asbestos cloth. The fire pans were fixed in place and filled with diesel oil as shown in Figure 97 and the camera lights were set up. The ventilation in the drift was reduced to 300 fpm (3.4 mph) at approximately 2:00 p.m., and held stable at that rate (by measurement as shown in Figure 98) until after the tests were completed. During the test series the temperature in the drift test area was 86^{O}F and the relative humidity was 71%. The fire tests were performed between 2:40 p.m. and 3:00 p.m., after the first shift crew left the mine and before the second shift crew was permitted to enter. The demonstration consisted of three fire tests precisely as described in the "request for variance," and as performed during the vehicle mock-up tests at Marinette, Wisconsin. The fires were set in small pans of various sizes located in various areas of the vehicle. The pan were filled with diesel oil up to the level of screens placed in each pan to act as heat sinks and splash preventors. The fires were ignited using a propane torch, heating the pan first and then the screens inside the pan until the diesel oil maintained ignition.



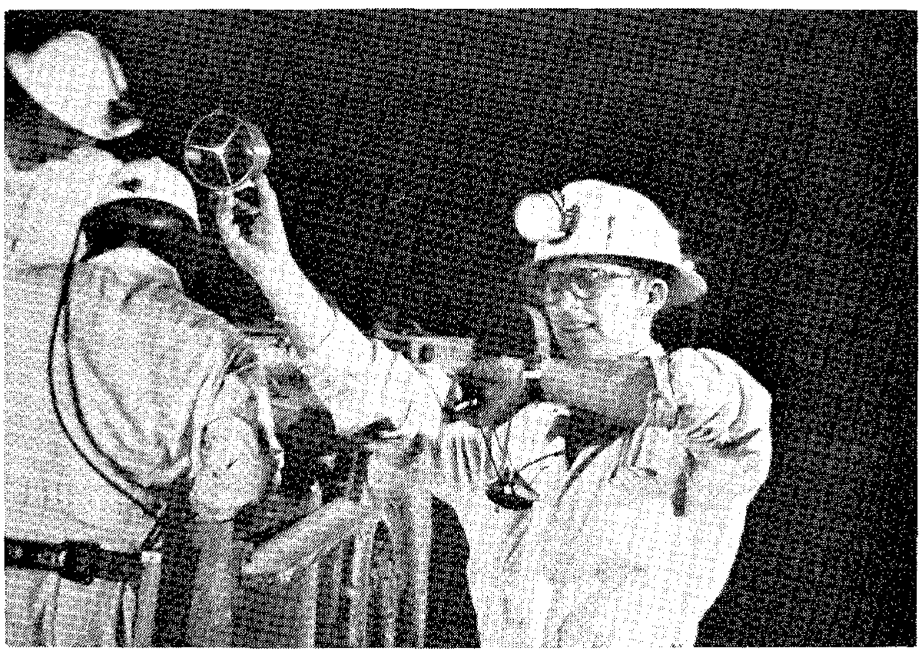
ENTERING TEST AREA EAST EXHAUST DRIFT

FIGURE 96



FILLING FIRE PANS WITH DIESEL OIL

FIGURE 97

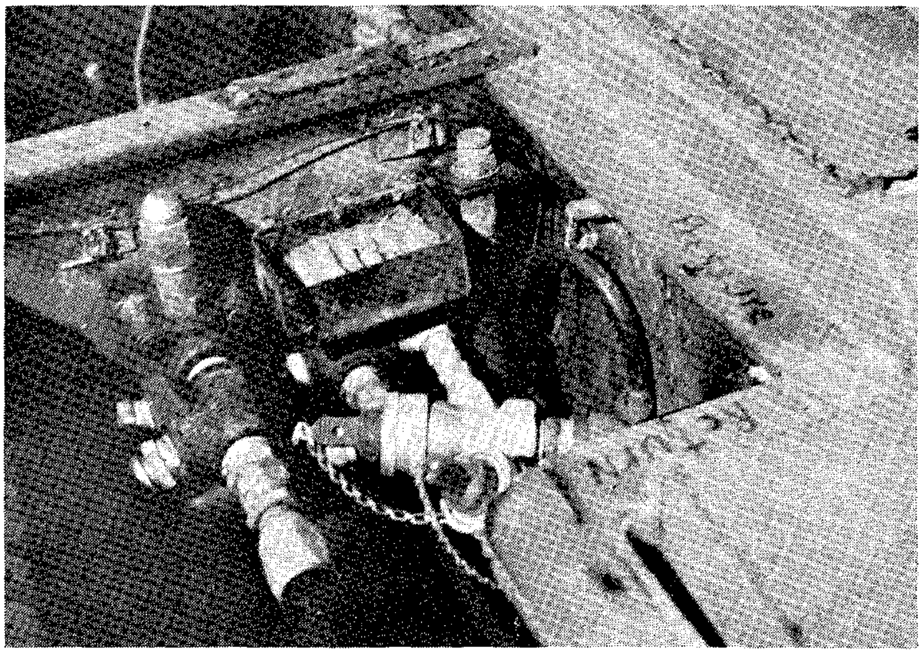


MEASURING AIR VELOCITY

FIGURE 98

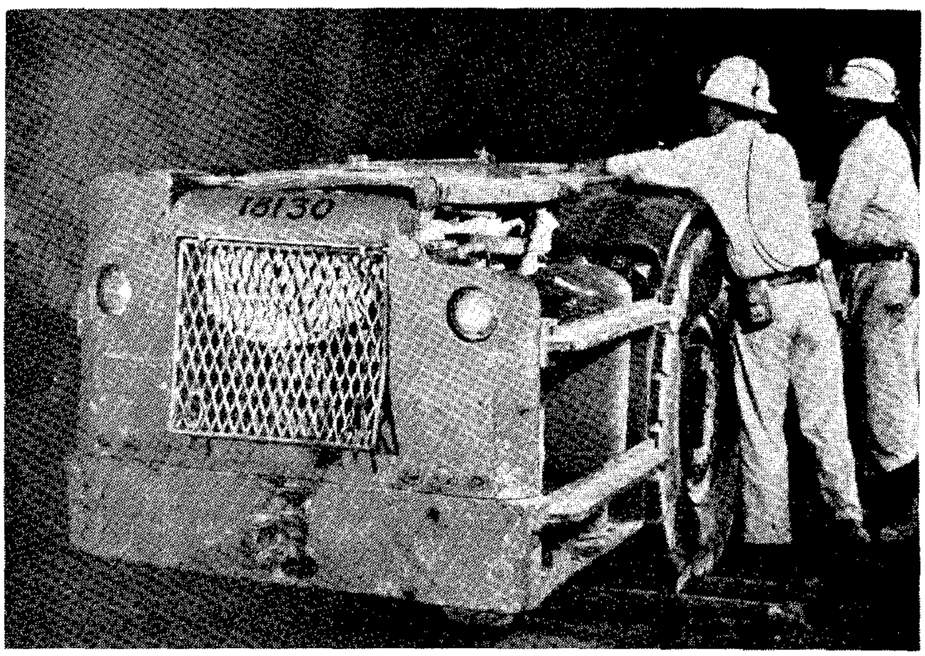
7.3.2.1 Test Number One

This test was performed to demonstrate that the detection and control system would sense and signal a fire in the articulation area of the vehicle. The pressure cartridge was removed from the electric actuation device to prevent the discharge of the dry chemical agent during this test. A small pan fire was initiated in the upper part of the articulation area. Figure 99 illustrates the fire pan and Figure 100 depicts the test conductors lighting the pan fire. The cover to the articulation cavity was then closed. Approximately ten seconds after the pan fire was ignited the detection wire sensed the presence of the fire as indicated by the lighting of the fire alarm light and the sounding of the audible fire alarm on the control console. At this point the test conductor extinguished the pan fire using a hand portable extinguisher. The AFCS performed its function as planned.



FIRE PAN IN ARTICULATION AREA

FIGURE 99

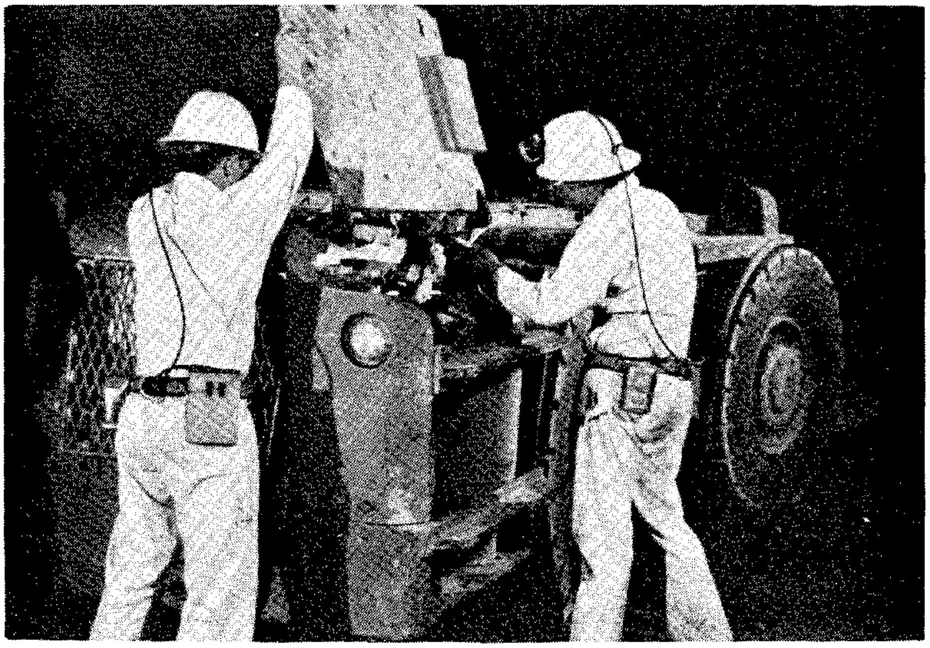


LIGHTING FIRE PAN IN ARTICULATION AREA

FIGURE 100

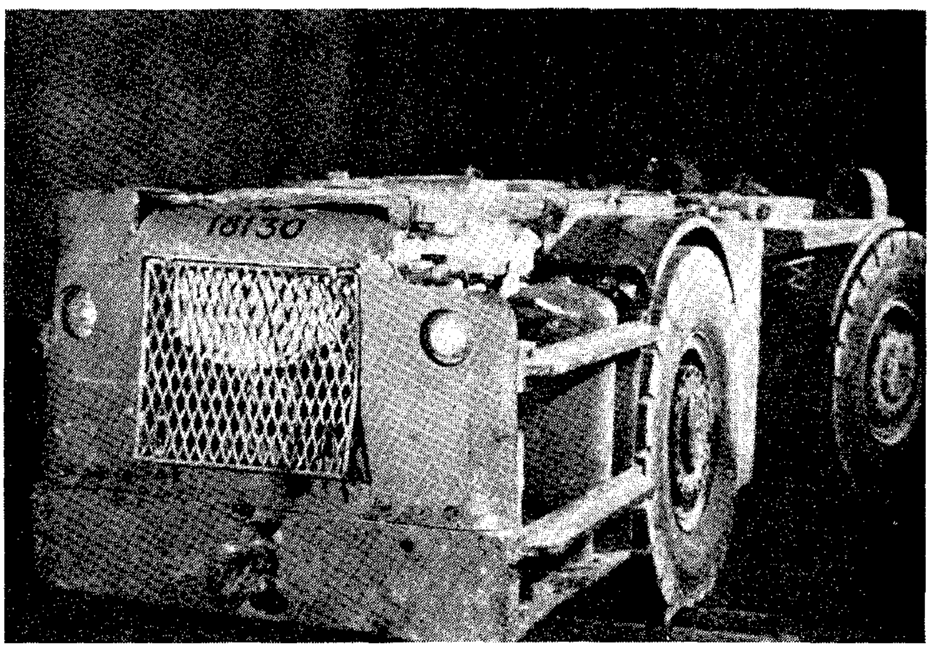
7.3.2.2 Test Number Two

This test was performed to demonstrate the automatic detection and suppression of a fire in the engine area of the vehicle. The pressure cartridge was replaced on the electric actuation device to make the AFCS fully automatic. Two pan fires were ignited in the engine area in the area of the manifold. This area was selected because the manifold is a hot metal part capable of igniting fuel or oil spills. One pan was located on top of the manifold and a second pan was located just above the manifold. Figure 101 illustrates the test conductors igniting the fire pans, and Figure 102 illustrates the pan fires. Approximately fourteen seconds after the fires were ignited the detection wire sensed the fire and caused the system to discharge the dry chemical agent. The pan fires were instantly extinguished. Figures 103 and 104 illustrate the discharge pattern, showing the vehicle fully enveloped in the cloud of dry chemical. The agent discharge time was approximately 10.5 seconds. The fully automatic detection and suppression of a fire in the engine area was demonstrated.



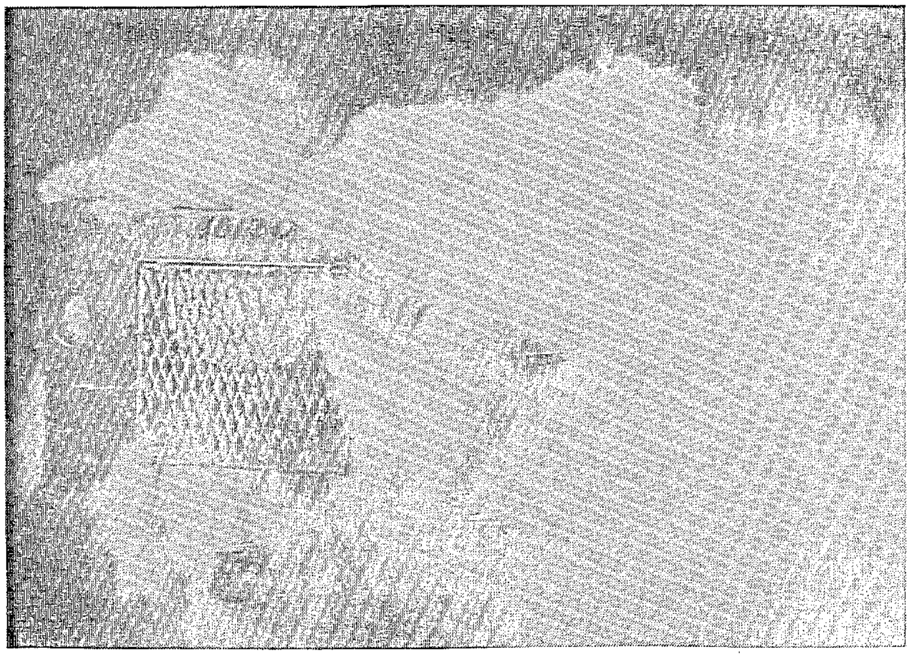
LIGHTING FIRE PAN IN ENGINE AREA

FIGURE 101



FIRE IN ENGINE AREA

FIGURE 102



DRY CHEMICAL DISCHARGE ON ENGINE FIRE, ~2 SECONDS

FIGURE 103

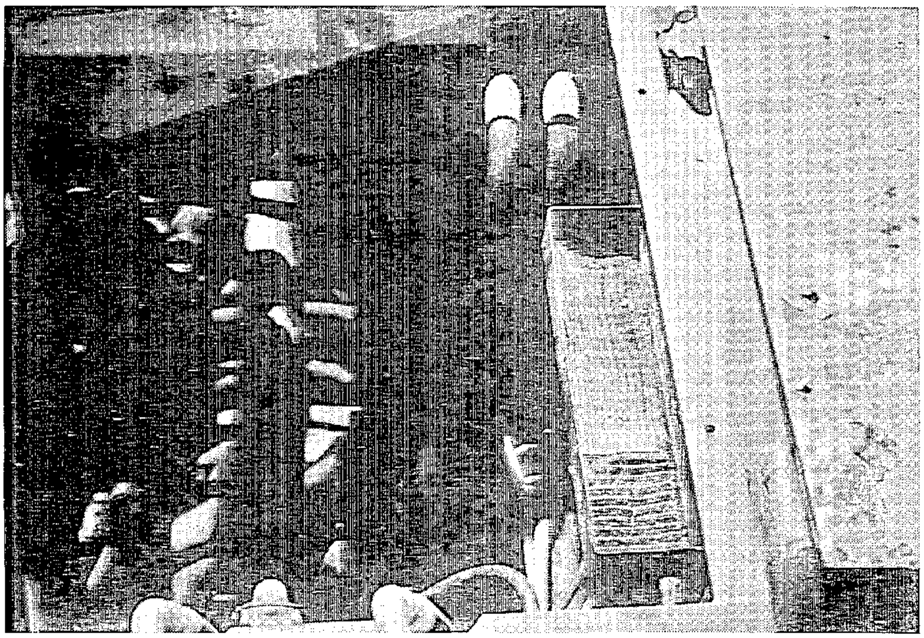
DRY CHEMICAL DISCHARGE ON ENGINE FIRE, ~6 SECONDS

FIGURE 104

7.3.2.3 Test Number Three

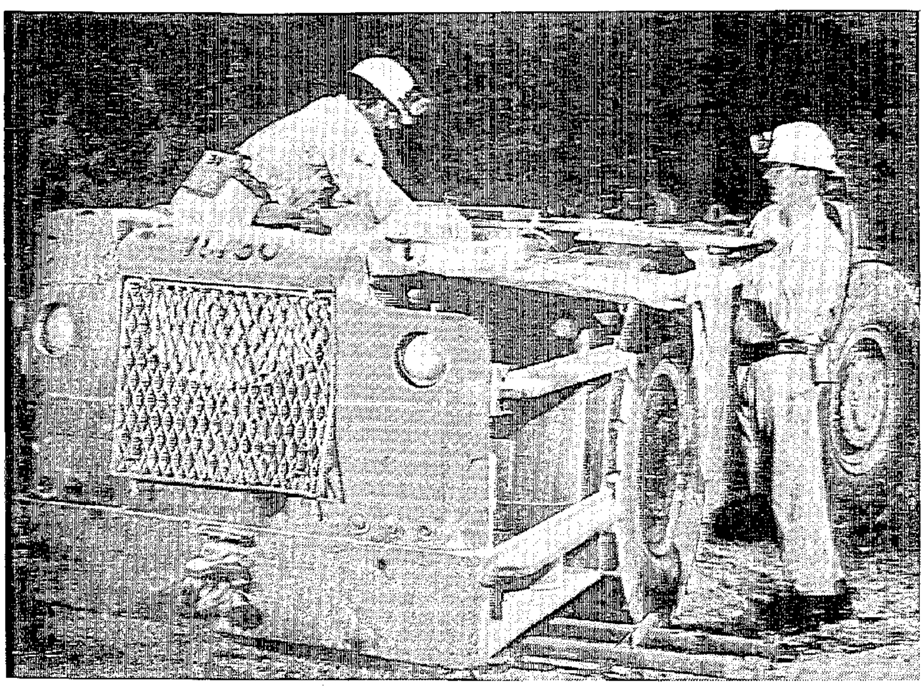
This test was performed to demonstrate the automatic detection and suppression of a fire in the transmission area of the vehicle. The actuation cartridge and the dry chemical container were replaced after Test Number Two to ready the AFCS. A pan fire was ignited near the top of the transmission area. Figure 105 illustrates the pan in location and Figure 106 illustrates the test conductors igniting the fire. The transmission cover was then placed over the transmission area. Approximately ten seconds after the fire was ignited the detection wire sensed the fire and caused the system to discharge. Figures 107 and 108 illustrate the discharge pattern, and the discharge characteristics were similar to that observed in Test Number Two. The fire was instantly extinguished by the agent. Figures 109 and 110 illustrate the tail end of the discharge, and show the rapid dispersion of the dry chemical agent in the drift. These pictures show that the operator would have been enveloped in the dry chemical cloud, but only for the ten-second discharge period. Miners in the area of the vehicle, even downstream, would not have experienced obfuscation from the dry chemical discharge. The discharge time was 10.5 seconds. The fully automatic detection and suppression of a fire in the transmission area was demonstrated.

The test group, as shown in Figure 111, inspected the vehicle after the test and released it to production.



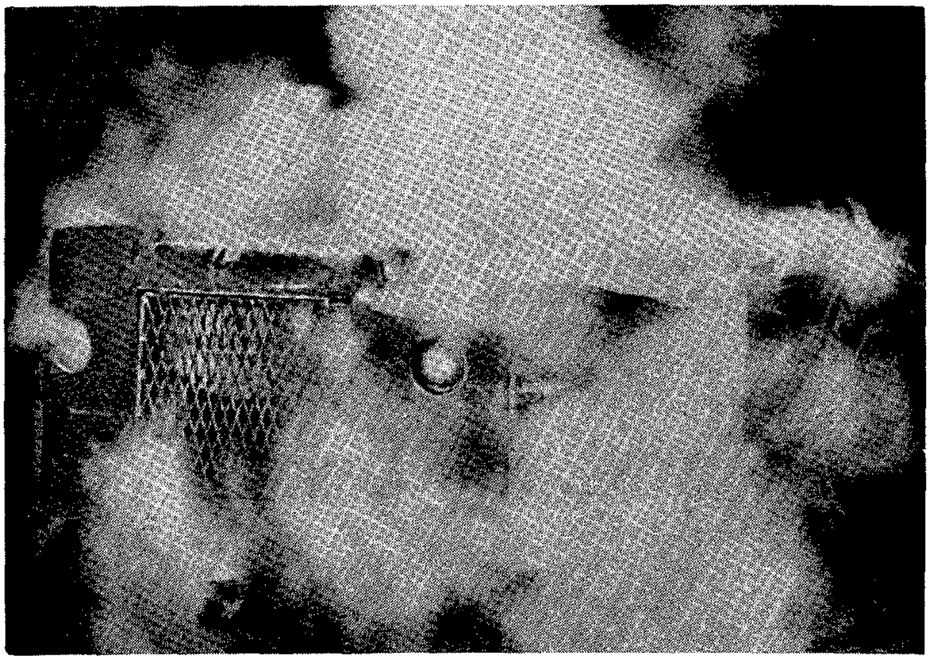
FIRE PAN IN TRANSMISSION AREA

FIGURE 105



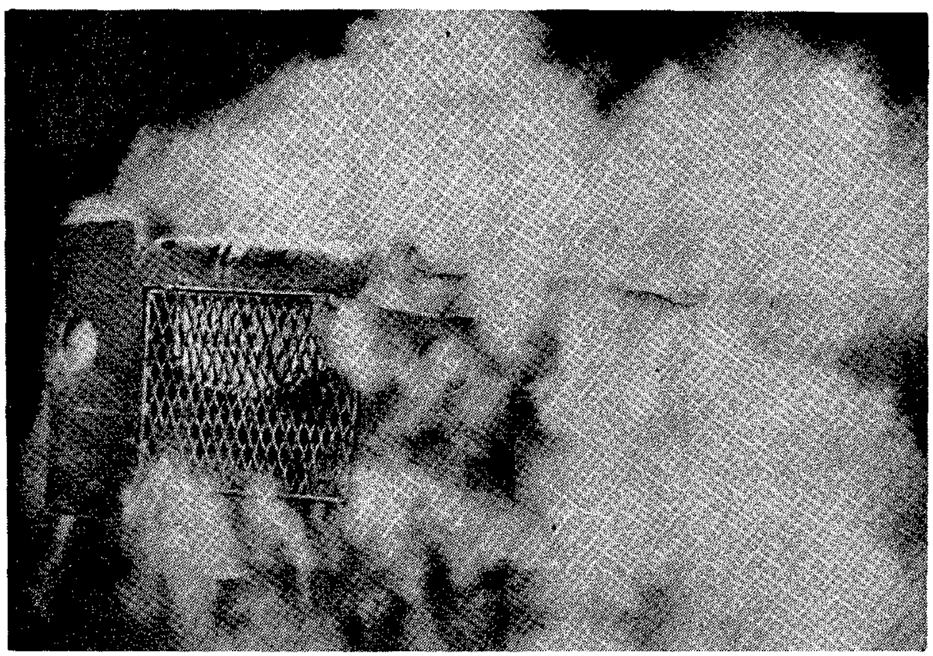
LIGHTING FIRE IN TRANSMISSION AREA

FIGURE 106



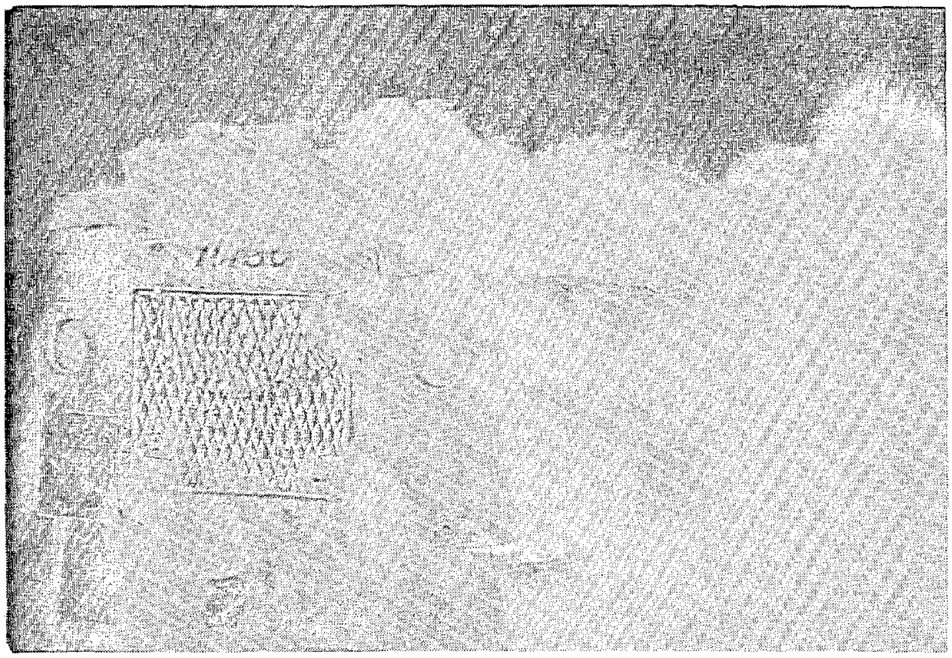
DRY CHEMICAL DISCHARGE, TRANSMISSION FIRE, ~2 SECONDS

FIGURE 107



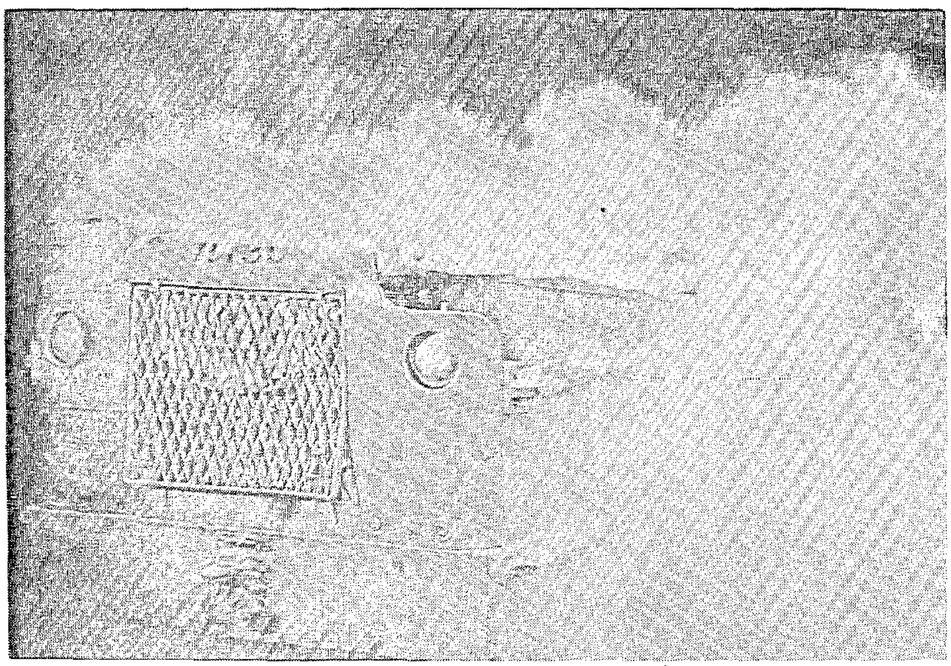
DRY CHEMICAL DISCHARGE, TRANSMISSION FIRE, ~6 SECONDS

FIGURE 108



DRY CHEMICAL DISCHARGE, TRANSMISSION FIRE, ~9 SECONDS

FIGURE 109



DRY CHEMICAL DISCHARGE, TRANSMISSION FIRE, ~12 SECONDS

FIGURE 110

7.3.2.4 Summary of Fire Test Results

- The AFCS performed in accordance with design specification during each of the tests.
- The AFCS demonstrated its capability of automatically sensing and suppressing vehicle fires in an underground mine environment.
- The discharge of dry chemical agent in the underground mine environment did not create a serious obfuscation problem. Only the vehicle driver would have had vision temporarily obscured during the dry chemical discharges.

8.0 SUBJECT INVENTIONS

There are no inventions created under this program. The developed system incorporates state-of-the-art hardware with modifications only as needed to adapt to the underground mine environment.

9.0 DELIVERABLE ITEMS

9.1 Hardware

The three hardware items, as described below, are being held at their present location, at the convenience of the Bureau, pending disposition of a proposal for further validation testing.

- One complete automatic fire protection system is installed on an ST-2B-LHD at the Hecla Lakeshore Project.

- One complete set of system spare parts is held at the Marinette, Wisconsin facility of The Ansul Company.

- The mock-up of the LHD vehicle is being held at the Marinette, Wisconsin facility of The Ansul Company.

9.2 Software

- The draft of the Final Report is submitted for review at the Phase IV Presentation at TCMRC on June 24, 1976. The final copies of the report will be due twenty (20) days after Bureau approval of the draft.

- A "Selection and Use Manual" will be delivered in July of 1976.

- Separate technical summary reports have been delivered for Phases I, II, III and IV.

- Monthly Technical Progress Reports and Financial Letter Reports have been provided throughout the program.

- Property Reports of accountable material have been provided and revised as needed to reflect changes.

APPENDIX A

PROJECT DATA FORMS

1. Mining Co. No.:_________(See list)

2. Mine site No.:__________(See list)

MINE DESCRIPTION FORM

3. Name of company and mine:

4. Address of main office:

5. Address of mine site:

6. Ores mined (check all that apply):

___a. copper	___i. potash
___b. fluorspar	___j. silver
___c. gold	___k. sodium carbonate
___d. gypsum	___l. trona
___e. iron	___m. tungsten
___f. lead	___n. uranium
___g. molybdenum	___o. zinc
___h. nickel	___p. other:________

7. Tons mined per day:__________

8. Stoping methods used:
   - ___a. room and pillar
   - ___b. cut and fill
   - ___c. caving (sublevel, block)
   - ___d. longwall
   - ___e. open stoping
   - ___f. other:______________

9. Ambient temperatures:__________

10. Humidity:______________

11. Lowest tunnel clearance height:______________

12. Average tunnel clearance height:______________

13. Production age of mine:____years

14. Number of shafts:____________

15. Methods of hauling and mucking used (check all that apply):
   - ___a. LHD's
   - ___b. rail
   - ___c. truck
   - ___d. belt
   - ___e. other:________

16. Employees underground:
   - a. 1st shift:__________
   - b. 2nd shift:__________
   - c. 3rd shift:__________
   - d. others:__________

17. Approximate dollar value of one day's production:
$__________

18. Average working depth of mine:____ft

19. Combustible substances present in (specify for each):
   - ___a. entrance:__________
   - ___b. haulage area:__________
   - ___c. working face:__________
   - ___d. maintenance area:__________
   - ___e. unused part:__________
   - ___f. other:__________

FIRE INCIDENT DESCRIPTION

INTERVIEW SUMMARY SHEET

1. Incident No.: _______ (See list)

2. Mining Co. No.: _____ (See list)

3. Mine site No.: ______ (See list)

4. Approximate date of incident: __________

5. Date form completed: ________________

6. Person completing form: ____________

7. Source of information concerning incident: (check one):
- ___ a. MESA report
- ___ b. mine records/reports
- ___ c. other literature
- ___ d. mine executive
- ___ e. mine safety director
- ___ f. mine maint. staff
- ___ g. other: ____________

8. Type vehicle that caused fire:

make: ________________

model: ________________

9. Equipment category:
- ___ a. airhammer
- ___ b. bolter
- ___ c. bulldozer
- ___ d. continuous miner
- ___ e. cutter
- ___ f. drill (hydraulic)
- ___ g. drill (non-hydraulic)
- ___ h. front end loader
- ___ i. grader
- ___ j. haulage truck
- ___ k. load-haul-dump (LHD)
- ___ l. locomotive/cars
- ___ m. mucker
- ___ n. personnel vehicle
- ___ o. powder loader
- ___ p. scaler
- ___ q. service/maint vehicle
- ___ r. shotcrete equipment
- ___ s. shuttle car
- ___ t. tunnel borer
- ___ u. other: ____________

10. Vehicle power source:
- ___ a. diesel
- ___ b. electric
- ___ c. other: ______________
- ___ d. not determined

11. Part of vehicle that caught fire:

____

____

12. Approx. dimensions of part of vehicle that caught fire: (circle units)

___in/ft x ___in/ft x ___in/ft

13. Was fire in driver's normal field of view at outbreak?
- ___ yes
- ___ no
- ___ not determined

Reason: ________________

14. Types of substances ignited (check all that apply):
- ___ a. fuel
- ___ b. hydraulic fluid
- ___ c. lubricant
- ___ d. wiring insulation
- ___ e. other: ____________
- ___ f. not determined

15. Source of heat for fire ignition:
- ___ a. electric wiring
- ___ b. electric cable
- ___ c. engine
- ___ d. exhaust manifold
- ___ e. muffler
- ___ f. exhaust scrubber
- ___ g. exhaust pipe
- ___ h. brakes
- ___ i. bearings
- ___ j. other: ____________
- ___ k. not determined

Incident No.:________

16. Causal or contributory factors (Check all that apply: enter a 1 if primary; 2 if contributing cause):
___a. operator error
___b. infrequent maintenance
___c. groundfall or similar incident
___d. equipment overheating
___e. improper maintenance
___f. other: ____________
___g. not determined

17. If operator error involved, describe:
____
____
____

18. Operator response to fire: ________
____
____

19. Location of fire relative to operator egress:
____
____

20. Vehicle operating status at start of fire:
___a. not operating
___b. between operations
___c. operating
___d. not determined

21. Vehicle location in mine at start of fire:
___a. entrance
___b. haulage area
___c. working face
___d. maintenance area
___e. unused part of mine
___f. other:______________
___g. not determined

22. Vehicle movement at start of fire:
___a. stationary
___b. moving toward entrance
___c. moving parallel to entrance
___d. moving away from entrance
___e. not determined

23. Typical duty cycle for vehicle involved: (circle units):
___min/hrs per ___min/hr cycle period,
for ___shifts per day.

24. Duration of fire incident: extinguished within:
___10 minutes or less
___11-30 minutes
___31-60 minutes
___61+ minutes
___not determined

25. Extent of fire during incident: (check all that apply):
___a. part of vehicle only
___b. entire vehicle involved
___c. secondary fires ignited
___d. not determined

26. Types of fire-extinguishing equipment used during incident (check all that apply):
___a. portable
___b. non-automatic installed
___c. automatic installed: ____________

27. If automatic fire-extinguishing equipment was installed on vehicle, it performed as follows during incident (check all that apply):
___a. sensed fire
___b. released extinguisher
___c. extinguished fire
___d. not determined

28. Fire incident consequences (check all that apply):
___a. human injuries (#=___)
___b. human fatalities (#=___)
___c. vehicle repairs
___d. vehicle replacement
___e. mine production slowdown
___f. mine shutdown (days=____
___g. other:______________

1. Mining Co. no.:______(See list)

2. Mining site no.:_____(See list)

3. Date form completed:______________

4. Person completing form (staff):____

____

FIRE HAZARD FACTOR RATINGS

INTERVIEW SUMMARY FORM

5. Information source:
   ___a. mine safety director
   ___b. mine executive
   ___c. mine maint. staff
   ___d. other:______________
   ____

6. Select and rank in order from (1) = most hazardous, to (10) = least hazardous, the ten types of mobile underground equipment most likely to have fires in the metal and non-metal mining industry:

   ___a. airhammer(rock breaker)
   ___b. bolter
   ___c. bulldozer
   ___d. continuous miner
   ___e. cutter
   ___f. drill (hydraulic)
   ___g. drill (non-hydraulic)
   ___h. front end loader
   ___i. grader
   ___j. haulage truck
   ___k. load haul dump (LHD)
   ___l. locomotive/cars
   ___m. mucker
   ___n. personnel vehicle
   ___o. powder loader
   ___p. scaler
   ___q. service/maintenance vehicle
   ___r. shotcrete equipment
   ___s. shuttle car
   ___t. tunnel borer
   ___u. other:________________
   ____

7. Rank in order from most (1) to least (5) fire hazard:

   ___a. fuel
   ___b. hydraulic fluid
   ___c. lubricant
   ___d. wiring insulation
   ___e. other:_______________
   ____

8. Rank in order from (1) most to (10) least fire hazard:

   ___a. electric wiring
   ___b. electric cable
   ___c. engine
   ___d. exhaust manifold
   ___e. muffler
   ___f. exhaust scrubber
   ___g. exhaust pipe
   ___h. brakes
   ___i. bearings
   ___j. other:_______________
   ____

9. Please rank fire causes from (1) most important to (6) least important:

   ___a. operator error
   ___b. infrequent maintenance
   ___c. groundfall or similar incidents
   ___d. equipment overheating
   ___e. improper maintenance
   ___f. other:_______________
   ____

1. Mining co. no.:________(See list)

2. Mining site no.:________(See list)

EQUIPMENT USAGE DESCRIPTION

INTERVIEW SUMMARY SHEET

3. Person completing form:________________

4. Date form completed:________________

5. Information source (if other than observation):________________

6. Equipment type observed (check one):

___a. airhammer (rock breaker)
___b. bolter
___c. bulldozer
___d. continuous miner
___e. cutter
___f. drill (hydraulic)
___g. drill (non-hydraulic)
___h. front end loader
___i. grader
___j. haulage truck
___k. load haul dump (LHD)
___l. locomotive/cars
___m. mucker
___n. personnel vehicle
___o. powder loader
___p. scaler
___q. service/maintenance vehicle
___r. shotcrete equipment
___s. shuttle car
___t. tunnel borer
___u. other:________________
____

7. While moving, vehicle vibration is equivalent to:

___a. paved road
___b. gravel road
___c. potholes
___d. other:________________

8. While stationary, vehicle vibration is:

___a. little or none
___b. medium vibration
___c. severe vibration

9. Shocks vehicle encounters (check all that apply):

___a. springs bottom out
___b. lurching
___c. loud impact sounds
___d. other:________________

10. Apparent leaks observed of:

	part of vehicle
___a. fuel	________________
___b. hydr.fluid	________________
___c. lubricant	________________
___d. other:	________________
	________________

11. Coating observed on outside of vehicle:

a)Substance:________________

b)Est. thickness:________________

12. Coating observed inside engine compartment:

a)Substance:________________

b)Est. thickness:________________

1. Mining co. no.:________(See list)

2. Mine site no.:_________(See list)

MAINTENANCE PROCEDURES DESCRIPTION

INTERVIEW SUMMARY FORM

3. Date form completed:_______________

4. Person completing form:____________

5. Source of information (if other than mine maintenance staff):

____

6. Types of equipment involved (check all types comprising maintenance group at mine):

- ___a. airhammer (rock breaker)
- ___b. bolter
- ___c. bulldozer
- ___d. continuous miner
- ___e. cutter
- ___f. drill (hydraulic)
- ___g. drill (non-hydraulic)
- ___h. front end loader
- ___i. grader
- ___j. haulage truck
- ___k. load haul dump (LHD)
- ___l. locomotive/cars
- ___m. mucker
- ___n. personnel vehicle
- ___o. powder loader
- ___p. scaler
- ___q. service/maintenance vehicle
- ___r. shotcrete equipment
- ___s. shuttle car
- ___t. tunnel borer
- ___u. other:___________________

  ____

7. Interval between inspections:

____

8. Interval between tuneups:_______

____

9. Interval between preventative maintenance efforts:__________

____

10. Interval between overhauls:_____

____

11. Cleaning practices:

a) Compound or substance used:______________________

b) Cleaning interval:_____________________________

12. Describe any corrosive chemicals or byproducts which collect on vehicles:________

____

1. Mining co. no.:_____(See list)

2. Mine site no.:______(See list)

MARKET FACTOR RATINGS

INTERVIEW SUMMARY SHEET

3. Date form completed:________________

4. Person completing form (project staff):

____

5. Source of ratings information:

___a. mine executive
___b. mine safety director
___c. mine maintenance staff
___d. mine purchasing staff
___e. other:_____________

6. Rank the relative importance of each of the following in deciding whether an automatic fire control system should be installed on a particular type of underground vehicle. Rank in order from (1) = most important, to (5):

___a. replacement cost of vehicle
___b. duty cycle of vehicle
___c. replacement/re-order time for vehicle
___d. insurance rate reductions
___e. other:__________________

7. Pick the five characteristics considered most important for any automatic fire control system which might become available to the industry as a result of this study. Rank these in order from (1)=most important, to (5):

___a. control system purchase price
___b. ease of installation for control system
___c. location of control system on vehicle
___d. operator training required to use control system (e.g. override procedures)
___e. frequency of maintenance for control system
___f. ease of maintenance for control system
___g. maintenance cost for control system
___h. control system reliability
___i. other:_______________________

8. What percentage of the purchase price of a vehicle would you pay for a 95% reliable automatic fire control system? _____%

9. What would be an acceptable cost for maintaining the automatic fire control system in working order? $______ per ______mo./year

10. How long do you usually expect an underground vehicle to last? ______mos./years

11. How long would you expect an automatic fire control system to last? ______mos./years

APPENDIX B

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APPENDIX C

INFORMATION CONCERNING EXISTING FIRE CONTROL SYSTEMS
AS SEEN ON UNDERGROUND MINING VEHICLES DURING THE MINE VISITS

INFORMATION CONCERNING EXISTING FIRE CONTROL SYSTEMS
AS SEEN ON UNDERGROUND MINING VEHICLES DURING THE MINE VISITS

SYSTEM NO. 1

1. General Information Concerning the Mine

   a. Type of Mining Operation: Not Available
   b. Type of Ore Mined: Copper

2. General Information Concerning the Protected Vehicle

   a. Type of Vehicle: Diesel-Powered Locomotive
   b. Vehicle Location (Operating) and Function: Operates in Haulage Drifts; Hauls Building Materials and Ore.
   c. Other Vehicles in Area: Others of the Same Type

3. General Information Concerning the Fire Control System

   a. Manufacturer of Fire Control System: Walter Kidde & Co., Inc.
   b. Number of Systems Per Vehicle: One
   c. Agent

      (1) Type: ABC Dry Chemical
      (2) Quantity Per Vehicle: One 20-Lb. Tank
      (3) Method of Containment: Unpressurized (Cartridge Operated) Steel Cylinder
      (4) Location of Container: In an Unused Sand Bin Area of the Vehicle

   d. Actuation

      (1) Type: $2\frac{1}{2}$-Lb. Manually Punctured CO_2 Cartridge. This is also the expellent gas cartridge. The gas is conveyed to the agent tank via a $\frac{1}{4}$" hydraulic hose.
      (2) Number of Actuators: One
      (3) Location of Actuators: In Operator's Compartment

   e. Agent Distribution System

      (1) No. of Nozzles: Four
      (2) Nozzle Type (Total Flooding or Local Application): Local Application, Cone-Shaped Spray Pattern. (Since the protected area is enclosed, a total flood situation would also be achieved.

(3) Location of Nozzles (Areas Protected):

1 Nozzle - Hydraulic Pump
1 Nozzle - Lower Front of Engine Fuel Tank
1 Nozzle - Track Area Under Rear of Vehicle
1 Nozzle - Fuel Injector System

(4) Method of Conveying Agent From Agent Tank to Nozzles: $\frac{1}{2}$" Flexible Hydraulic Hose and Rigid Pipe ($\frac{1}{2}$" I.D.)

f. Maintenance Procedures: The system had just recently been installed. No maintenance records had been generated.

g. System Costs:

Purchase Cost	$350.00
Installation Costs	250.00
Maintenance Costs (Incurred To-Date)	----
Replacement Costs Today (System Only)	390.00

h. Performance History:

Date Installed		May 1975
Actual Events:	Fires	None
	False Discharges	None
	Test Discharges	None

4. Comments Concerning the General Overall Effectiveness and Reliability of the System

a. Mine Operator's Opinion: Believes system would perform well but has never had to test it.

b. Contractor's Opinion: Basically, the system is installed well. The one nozzle that points to the track area under the vehicle is useless, as there is no hazard there. The other three should be able to control most fires in the forward part of the engine compartment and the total flooding effect may help with the rear of the compartment.

The tank is well protected, yet, in its location it is also very difficult to get at for inspection, maintenance, or recharge.

For the sake of reliability and safety, on a machine this large there should be at least one additional actuator located at the opposite end of the vehicle from the existing actuator in the operator's compartment.

SYSTEM NO. 2

1. General Information Concerning the Mine

   a. Type of Mining Operation: Cut and Fill Technique
   b. Type of Ore Mined: Lead, Zinc and Silver

2. General Information Concerning the Protected Vehicle

   a. Type of Vehicle: Low Profile Haulage Vehicle
   b. Vehicle Location (Operating) and Function: Operates in Main Haulage Drifts Performing Various Hauling Duties
   c. Other Vehicles in Area: Haulage Vehicles, Servicing Vehicles, and LHD's.

3. General Information Concerning the Fire Control System

   a. Manufacturer of Fire Control System: The Ansul Company
   b. Number of Systems Per Vehicle: One
   c. Agent:

      (1) Type: ABC Dry Chemical
      (2) Quantity Per Vehicle: One 30-Lb. Tank
      (3) Method of Containment: Unpressurized (Cartridge Operated) Steel Cylinder
      (4) Location of Container: In Front of Engine's Heat Exchanger (Radiator)

   d. Actuation

      (1) Type: .84-Lb. Manually Punctured N_2 Cartridge The gas from this cartridge serves to actuate a one-lb. CO_2 expellent gas cartridge which is located on the side of the agent tank.
      (2) Number of Actuators: One
      (3) Location of Actuators: Operator's Compartment

e. Agent Distribution System

(1) Number of Nozzles: Four

(2) Nozzle Type (Total Flooding of Local Application): Combination of Local Application and Total Flood. The Spray Pattern is a 160° Fan-Shape.

(3) Location of Nozzles (Areas Protected):

2 Nozzles - One on Each Side of Engine
1 Nozzle - Belly Pan of Engine
1 Nozzle - Dashboard in Operator's Compartment

(4) Method of Conveying Agent From Agent Tank to Nozzles: ½" Flexible Hydraulic Hose

f. Maintenance Procedures: A yearly check is made of the dry chemical, bursting disc, and gas cartridge weights. The system has not been installed long enough for its first check.

g. Approximate System Costs:

Purchase Cost	$250.00
Installation Costs	350.00
Maintenance Costs (Incurred To-Date)	----
Replacement Costs Today (System Only)	250.00

h. Performance History

(1) Date Installed: January 1975

(2) Actual Events:

Fires: One dashboard fire has been extinguished with the system.

False Discharges: Two false discharges have been recorded. The reason for these is the location of the agent tank. Extremely hot air flows from the heat exchanger past the expellent gas cartridge of the agent tank. The cartridge becomes hot, blows its safety disc, and discharges the system. The problem could be remedied by rotating the tank so that the expellent gas cartridge is faced away from the heat flow or by locating the tank elsewhere.

(3) Test Discharges: None

4. Comments Concerning the General Overall Effectiveness and Reliability of the System

a. Mine Operator's Opinion: Very satisfied with the system, especially since it put out one actual fire.

b. Contractor's Opinion: Basically, the system is installed well. The three engine compartment nozzles completely blanket this area of the vehicle, providing adequate protection for most fires. The dashboard nozzle, on the other hand, would provide greater protection if located either at the torque converter or the articulation point. The dashboard fire is minor and is easily extinguished by either turning the power off or with the aid of a hand portable unit (a frequent occurrence prior to the system installation, according to the mine operator).

For many reasons it would be better if the agent tank were not located in the path of the heat exchanger's hot air flow. This high temperature conditions is not good for the dry chemical and, as previously explained, is the cause of the false discharges.

Also, for reasons of reliability and safety, there should be a second actuation device located at the opposite end of the vehicle from the existing actuator in the operator's compartment.

APPENDIX D

PLANS FOR FIELD DEMONSTRATION

A G R E E M E N T

This Agreement entered into as of 30 April 1976, between The Ansul Company, a Wisconsin corporation with its principal office in Marinette, Wisconsin (hereinafter Ansul) and Hecla Mining Company, an Idaho corporation with an office in Casa Grande, Arizona (hereinafter Hecla).

W I T N E S S E T H

WHEREAS Ansul entered into Contract HO252038 with the United States Bureau of Mines whereby Ansul will test certain fire detection and suppression devices for use on underground vehicles; and

WHEREAS Ansul has inspected the Lakeshore Project Mine, Casa Grande, Arizona which is operated by Hecla; and

WHEREAS, Ansul has determined that a portion of the Lakeshore Project Mine is suitable for such testing; and

WHEREAS Hecla has consented to Ansul to conduct such testing at the Lakeshore Project Mine.

NOW THEREFORE, the parties hereto agree as follows:

1. Hecla will permit Ansul to conduct the testing required by Phase II of Bureau Contract HO252038 attached to and made a part of this Agreement as Exhibit A, at its Lakeshore Project Mine in the East Exhaust Drift at the five hundred feet level.

2. Work to complete such testing shall commence on or about May 7, 1976 and last for a period not to exceed three weeks.

3. Hecla will permit Ansul to enter the Lakeshore Project Mine and to set up underground test equipment and conduct such tests as are required by Phase II as set forth in Exhibit A. Hecla will assist with personnel and equipment as needed to transport, set up the underground test, and for Ansul to conduct the aforementioned test. Ansul and Hecla will comply with all federal and state safety requirements.

4. Notwithstanding the fact that Ansul will have principal responsibility for conducting the test, Hecla reserves the right to disallow the test in the event that a management representative determines, in his sole judgment, that the location of the test or the manner in which the test is to be conducted either appears to endanger life or property or unduly disrupts mining activity.

5. Dry chemical agent furnished by Hecla and used in the performance of the testing will be invoiced to Ansul in accordance with Ansul's customary list price.

6. Hecla shall furnish equipment as defined in Exhibit B for use during the performance of this Agreement at no cost to Ansul. Said equipment is the property of Hecla after completion of the period of performance of this Agreement.

7. Hecla shall issue no statement to news media regarding the tests without the written approval of Ansul designated representative. Ansul shall issue no statement to news media regarding Hecla's participation in the tests without the written approval of Hecla's designated representative.

8. All notices concerning this Agreement shall be deemed to have been given when deposited in the United States mails, registered with the proper postage prepaid, addressed to the following parties:

If to Hecla to:

Hecla Mining Company

P.O. Box 493

Casa Grande, Arizona 85222

Attention: Claude Huber

If to Ansul to:

The Ansul Company

One Stanton Street

Marinette, Wisconsin 54143

Attention: Gene R. Reid

9. Ansul shall be solely responsible for and shall hold Hecla free and harmless from, and hereby indemnifies Hecla against, any and all claims, demands, causes of action, loss, cost, damage and expense, including reasonable attorney's fees, arising out of or in connection with injuries (including death) to any and all persons (including but not limited to employees of Hecla and Ansul) and damages to property, in any way sustained, or alleged to have been sustained as a result of gross negligence, willful misconduct or bad faith on the part of Ansul, its agents and employees, and its subcontractors in performance of this Agreement.

10. Hecla shall be solely responsible for and shall hold Ansul free and harmless from, and hereby indemnifies Ansul against any and

all claims, demands, causes of action, loss, cost, damage and expense, including reasonable attorney's fees, arising out of or in connection with injuries (including death) to any and all persons (including but not limited to employees of Ansul and Hecla) and damages to property, in any way sustained, or alleged to have been sustained as a result of gross negligence, willful misconduct or bad faith on the part of Hecla, its agents and employees, and its subcontractors in performance of this agreement.

11. Hecla will provide Ansul with a certificate of insurance evidencing coverage for the underground vehicle to be provided by Hecla for use in connection with the requirements of Phase II testing, Exhibit A, and such certificate shall list Ansul as an additional insured.

IN WITNESS WHEREOF, the parties hereto have executed this Agreement as of the day and year first above written.

THE ANSUL COMPANY

By William A. Rickel
William A. Rickel
General Manager
Fire Protection Group

Date 4/30/76

HECLA MINING COMPANY

By [illegible]

Title [illegible]

Date 5/10/76

201

THE ANSUL COMPANY

MARINETTE, WI 54143, TELEX 26-3433, TELEPHONE (715) 735-7411

March 18, 1976

Mining Enforcement & Safety Administration
Department of the Interior
4015 Wilson Boulevard
Arlington, Virginia 22203

ATTENTION: Mr. Robert E. Barrett, Administrator

Gentlemen:

SUBJECT: Application for Variance

REFERENCE: USBM Contract HO252038, "Development of Automatic Fire Protection System for Mobile Underground Metal Mining Equipment"

In accordance with the requirements of the Interior Health and Safety Standards for Metal and Non-Metal Mines, Standard 57.0 of Title 30, Code of Federal Regulations, The Ansul Company, in cooperation with the Hecla Mining Company in Casa Grande, Arizona, requests a variance to Standard 57.4-58.

The Ansul Company is currently working on the reference USBM contract. The purpose of the contract is to develop and demonstrate in an underground mine site a low cost, reliable, automatic fire protection system for Mobile Underground Metal Mining Equipment. As shown on the attached milestone chart, we have completed Phase II, and are in the process of performing system functional and fire tests to demonstrate the system capability using a prototype system installed in a vehicle mock-up. Following this fire test series the prototype system will be installed on an underground mine vehicle and demonstrated by a fire test in an underground mine during the period of May and June 1976. This later test requires the building of a controlled fire underground; thus, a variance from Standard 57.4-58 is requested.

The following detailed information is provided in accordance with the requirements as stated in Section 57.24.4:

(a) A temporary variance is requested from mandatory standard 57.4-58 of Title 30, Code of Federal Regulations, revised as of July 1974, which reads as follows:

"Mandatory. Fires shall not be build underground; open flame torches and candles shall not be left underground."

(b) In order to demonstrate the effectiveness of the automatic fire protection system on a mobile underground vehicle, a fire test demonstration must be performed on an actual vehicle operating underground. The test is a requirement of Contract HO252038. Up to three controlled pan fires will be set on the test vehicle and the automatic system will detect and extinguish the fires. A mine fire safety crew will be on the scene with back-up fire fighting equipment. Care will be taken to remove or protect any non-involved combustibles from the area. Prior to the underground test a series of fire tests will be performed above ground on the vehicle mock-up to insure system effectiveness.

(c) The test will be conducted in the 500 level East Exhaust Drift which is the main exhaust drift for the 500 level. Two exits from the test area are available. The drift is 500 ft. long and the test will be performed 200 ft. into the drift. At the exhaust end of the drift, 300 ft. from the test area the main exhaust vent carries the air directly to the surface. At the base of this vent there is a fuel storage area. The drift slopes away from the exhaust vent.

(d) The fire test demonstration cannot be performed without a temporary variance from Standard 57.4-58 which prohibits the building of underground fires.

(c) The variance is requested for the period of May and June 1976.

(f) The test will be conducted during a shift change. During this period approximately seventy-five employees will be in the non-affected areas of the mine. There will be up to twenty persons in the area affected by the test. These will include five Ansul employees, five Bureau of Mines guests, four Hecla observers, and a six man mine rescue team of Hecla employees.

(g) Access of personnel to the fire test area will be rigidly controlled to insure that only personnel involved with the test are present during the demonstration. From a long-range viewpoint, the purpose of the research program is to alleviate the potential hazard to mine workers from fires which occur on mobile underground vehicles.

(h) Mr. Gene R. Reid, who signs this application, is the Ansul Program Manager for USBM Contract HO252038.

(i) In accordance with 57.24-3, a copy of this application for variance is being submitted to Mr. James H. Hunter, Mine Manager of the Hecla Mining Company, Casa Grande, Arizona, with a request that notice be given to all persons that would be affected by the variance (copy of letter attached). In addition, copies of this letter are being sent to the following:

Mr. Tom Lukins, District Manager
Western District Office
Mining Enforcement & Safety Adminstration
620 Central Avenue
Alameda, California 94501
(415) 273-7457

Mr. Levi Brake
Sub-District Manager
MESA Suite 706
2721 North Central Avenue
Phoenix, Arizona 85004
(602) 261-3233

Mr. Guy Johnson, Technical Project Officer
Underground Mine Development and Production
Twin Cities Mining Research Center
U.S. Department of Interior, Bureau of Mines
Post Office Box 1660
Minneapolis, Minnesota 55111

All of the above letters are being transmitted simultaneously with this letter.

If there are any further questions or areas requiring clarification, please contact the undersigned at (715) 735-7411.

Very truly yours,

THE ANSUL COMPANY

Gene R. Reid
Program Manager

GRR:dms
attachments: Milestone Chart
Letter to James H. Hunter

United States Department of the Interior
MINING ENFORCEMENT AND SAFETY ADMINISTRATION
4015 WILSON BOULEVARD
ARLINGTON, VIRGINIA 22203

In Reply Refer To:
EMS - MN

April 1, 1976

Mr. Gene R. Reid
Program Manager
The Ansul Company
Marinette, Wisconsin 54143

Dear Mr. Reid:

This is in response to your letter of March 18, addressed to the Administrator, requesting a permanent variance from Federal mandatory standard 57.4-58.

We are asking Mr. T. C. Lukins, District Manager, Western District, Metal and Nonmetal Mine Health and Safety, Mining Enforcement and Safety Administration, to initiate an investigation of your contentions.

This variance request of necessity must be issued to the Hecla Mining Company as the operator of the mine. We will ask that this variance, when investigated and drafted, specify the Hecla Mining Company and Lakeshore Mine as the receiver of the variance.

We must also bring to your attention that since Arizona is a State Plan State, the State must issue the variance with concurrence and approval by MESA. We will ask that Mr. Lukins transmit a copy of this variance to the State and ask that they conduct the necessary investigation. We will participate with the State to assist in their investigation.

A decision on your particular situation will be made after all factors have been investigated and considered.

Sincerely yours,

Arthur P. Nelson
Assistant Administrator
Metal and Nonmetal Mine
Health and Safety

OFFICE PHONE 271-5971

HOME PHONE 268-2447

State Mine Inspector

BERT C. ROMERO
PHOENIX, ARIZONA 85007

Mine Identification No. 02-00498

Date April 15, 1976

Western (District)	Phoenix (Subdistrict)
Hecla Mining Company (Company Name)	Lakeshore Mine (Mine Name)

Box 493	Casa Grande	Pinal	Arizona
(Mailing Address)	(Town)	(County)	(State)

Pursuant to Section 57.24-1 of Part 57, Title 30, Code of Federal Regulations revised as of July, 1974, and the delegation of authority to grant variances from mandatory health and safety standards contained in part 57 by the Director on January 13, 1971 (36 F.R. 836, January 19, 1971), the undersigned after due consideration of all factors involved permits a variance from Federal Mandatory Standard 57.4-58 which will allow the Ansul Company to build a controlled fire underground for the purpose of demonstrating and documenting the results of an automatic fire protection system for mobile underground metal mining equipment being developed under USBM Contract HO252038, and subject to the following precautions in addition to those set forth in the variance request:

Conditions and Restrictions

1. This variance applies only to Federal mandatory standard 57.4-58.

2. Area of Mine: The test will be conducted in the 500 level East Exhaust Drift approximately 200 feet into the drift (exhaust end). Air entering into this drift will exhaust directly to the surface through the No. 6 ventilation shaft.

3. Period of Time: The period of time for which this variance is permitted is only during the day set (target date May 13) in May, 1976, and shall be accomplished as near to the shift change, 3:30 p.m., as practical and completed within a reasonable time (expected to be completed by 4 p.m.).

4. Other:
   (a) Insure that only persons involved with the test are present during the demonstration in the area affected by the test. This will include Ansul employees, Bureau of Mines guests, Hecla observers, a six-man mine rescue team equipped with 2 hour approved breathing apparatus, and MESA and State representatives, also equipped with approved breathing apparatus.

   (b) The six members of the Lakeshore mine rescue team shall be selected members who are well-trained in firefighting techniques, and they shall have with them at the test site adequate firefighting equipment.

   (c) All persons shall have self-rescuers and be trained in its use and shall have been instructed in mine emergency procedures. (Ansul and BOM personnel can be trained at the mine property before going underground).

   (d) A designated qualified person shall monitor the mine atmosphere at the test site, and in the event that dangerous concentrations of toxic gases are detected, or that the demonstration equipment fails, all persons shall immediately evacuate to the surface via the fresh air drifts. Only the mine rescue team should remain to deal with the situation and react to whatever orders the team captain feels are necessary to alleviate any danger to all persons.

   (e) Tests must be made of the affected mine atmosphere for a sufficient period of time after the test to determine that products of combustion do not remain.

5. During the inspection of the test site by MESA and the State mine inspector's personnel the following recommendations were made to company personnel: (these recommendations shall be complied with before the demonstration is performed).

   (a) The demonstration vehicle shall be parked securely either by parking it into the rib of the drift or other equivalent positive methods. (This is necessary due to the upward slope of the test site drift).

   (b) The 110-volt electrical powerline which is installed in the back of the drift shall be de-energized or removed.

   (c) The 1400 FPM velocity going through the drift shall be reduced to at least 300 FPM. (The Hecla Mine ventilation engineer stated that this would be possible without affecting any other work area in the mine; in other words, the same amount of air would be entering the mine, but would be exhausted elsewhere).

   (d) At the exhaust-end of the drift, approximately 300 feet from the test area, there is a fuel storage area located at the base of the vent shaft.

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This shall have the following:

1. All empty barrels removed.
2. All debris and spilled oil shall be cleaned up.
3. The trash cans shall be removed.
4. The small oil sump shall be cleaned.
5. Only a minimum amount of fuel shall be in the tank.

REVOCATION AND CANCELLATION

Failure to observe any or all the conditions and restrictions set forth shall be deemed cause for the immediate revocation and cancellation of this variance by the District Manager.

FINDINGS

Under these circumstances the health and safety of all persons which Federal Mandatory Standard 57.4-58 is designed to protect will be no less assured.

NOTICE

A copy of this variance shall be posted on the Company bulletin board or in some other appropriate place at the mine to give adequate notice to the employees, and the variance shall be kept on file in the mine office and subject to public inspection by any interested person(s) at all reasonable times so long as the variance remains in effect.

I concur

/s/ T.C. Lukins
T.C. Lukins
District Manager

I concur

I recommend the granting of the above variance.

/s/ A.P. Nelson
A.P. Nelson
Assistant Administrator--Metal & Nonmetal Mine Health and Safety

/s/ Bert C. Romero
Bert C. Romero
State Mine Inspector

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8/5/76

MAY 10, 1976

MEMORANDUM TO: All Underground Personnel

FROM: Claude Huber

SUBJECT: Ansul Fire Test Notification

On Thursday, May 13, 1976, between day and swing shift a joint Hecla-U.S.B.M. Ansul test will be conducted on the 500 Level in the East Exhaust Drift. This test will involve setting a small controlled fire on an ST-2B to determine if a new automatic fire sensing and suppression system will work under mine conditions.

This controlled fire will have no effect on your safety, or air quality. The test will be in the main exhaust air stream and fire crews and equipment will standby as an added precaution.

Both the State and Federal Mine Inspectors have been notified and personnel from each agency will observe the test.

Please indicate that you have read and understand this memo by placing your signature and employee number below:

CH:br

SIGNATURE EMPLOYEE #

LAKESHORE MINE
HECLA MINING COMPANY

Procedure for Underground Fire Test at the Hecla Lakeshore Project

Pre-Test Briefing

Describe Test Sequence (Ansul)

(Film 9 minutes)

Safety Procedures (Hecla)

Test Procedure

The tests will occur in the East Exhaust Drift at the 500 level on a Wagner ST2B-LHD with the prototype Automatic Fire Control System installed on the vehicle.

Test Number One

The cartridge will be removed from the electric actuation device to prevent the discharge of the dry chemical. A small pan fire will be set in the articulation area to demonstrate that the detection system will actuate. When the fire is sensed by the detection loop the "fire condition" will be indicated by the visual and audible alarms on the control console. After the "fire condition" is noted the pan fire will be extinguished with a hand portable fire extinguisher.

Test Number Two

The cartridge will be reinstalled on the electric actuation device and the automatic fire control system will be fully operational. A large pan fire beside the exhaust manifold and a small pan fire above the exhaust manifold will be ignited. When the detection device senses the fire the automatic fire control system will discharge and extinguish the fires.

Test Number Three

The dry chemical system will be recharged. A small pan fire will be set inside the transmission area. When the detection device senses the fire the automatic fire control system will discharge and extinguish the fire.

General Notes

- The large pan is 4" x 36" with screens in the pan to the top of the liquid level to minimize splashing. The pans will be filled to the top of the screens with diesel fuel.
- The small pans are 4" x 18", but otherwise as described above.
- The fires will be ignited by application of a propane torch to the diesel oil and screen.
- Ansul photographers (2) will take motion and still photography during all tests (and discharges on day preceding thé fire tests).
- The vehicle engine will not be operating during the fire tests and the engine will be cold.
- The Ansul test conductor and technician will act as back-up firefighters.
- The Hecla Safety Officer will have the authority to assume control of the test from the Ansul test director at any time be decides that there is a safety problem.

GRR:dms
4/5/76