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USBM Contract No. H0122086

SUPPRESSION OF FIRES ON UNDERGROUND COAL MINE CONVEYOR BELTS

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FOREWORD

This report was prepared by Walter Kidde & Company, Inc., Belleville, N.J. under USBM Contract No. H0122086. The contract was initiated under the Coal Mine Health and Safety Research Program. It was administered under the technical direction of the Pittsburgh Mining and Safety Research Center with Mr. Donald W. Mitchell acting as the technical project officer. Miss Kathryne M. Hughes 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 28, 1972 to December 1, 1973. This report was submitted by the authors on September 13, 1974.

This technical report has been reviewed and approved.

ABSTRACT

This program involves the evaluation of means for suppressing fires on underground coal mine conveyor belts. Full scale conveyor belt fire tests were conducted to determine the requirements of automatically actuated water sprinkler, high expansion foam, and multi-purpose dry powder extinguishing systems, and of various fire detection devices, necessary to adequately protect underground belt heads. The program included the development of a suitable full scale conveyor belt test fire, conducting of fire tests in which extinguishing and detection systems and equipment were evaluated, and testing to evaluate the effects of the coal mine environment on detection equipment.

Preliminary testing conducted to develop a suitable test fire revealed that fire can propagate on some conveyor belting classified as fire-resistant. New fire-resistant PVC and new non-fire resistant rubber belts were used in the full scale fire tests. These tests indicated that a single branch line sprinkler system with relatively low water pressure provides adequate belt head protection. High expansion foam and multi-purpose dry powder extinguishing systems as presently specified by regulation were found to be suitable for belt head protection, although care is required with powder systems to assure adequate distribution. Thermal type detection devices were found to be most practical for conveyor belt protection, with combustion products and optical detection methods having serious disadvantages.

SUBJECT INVENTIONS

No inventions were developed in association with this contract.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont)

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

Experience has shown that almost 15 percent of all underground coal mine fires in the United States result from ignition of conveyor belts.[1] The area in which the concentration of potential sources of ignition is usually the greatest is the belt head, since this area typically includes the belt drive, hydraulic and electrical equipment, as well as pulleys, rollers, and the potential for coal dust accumulations that also exist elsewhere along the conveyor.

Present regulations require fire extinguishing coverage in belt head areas. The extent of coverage required is 50 ft of conveyor for fire resistant belting and 150 ft of conveyor where non-fire resistant belting is involved.[2] The regulations also specify some details relative to quantities and rates of discharge of extinguishant. With regard to detection, the regulations spell out spacing requirements for thermal point type detectors, and require that any other type detection used provide equivalent protection.[3]

The primary objective of this program is to evaluate the existing regulations and to make recommendations for change and/or further definition of conveyor belt fire protection coverage where the need for such change is indicated.

The work performed under this contract was conducted both in above ground test galleries designed to simulate underground belt haulageways, and in an actual operating coal mine in Cambria County, Pennsylvania. All testing involving fire was conducted in the test galleries, while tests in the operating mine involved a study of the effects of the underground coal mine environment on fire protection equipment. This study included the placement of various sensing devices in the belt head area of an operating belt haulageway and functionally testing the devices after exposure to this environment for several months.

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[1] Mitchell, Donald W., Edwin M. Murphy, Allan F. Smith, and Samuel P. Polack. Fire Hazard of Conveyor Belts, Bureau of Mines Report of Investigation 5632, 1967, p. 1.

[2] "Rules and Regulations, Section 75.1101," Federal Register, Vol. 35, No. 226 (November 20, 1970), pp. 17918 - 17920.

[3] "Rules and Regulations, Section 75.1103," Federal Register, Vol. 37, No. 159 (August 16, 1972), pp. 16545, 16546.

2. COMPARISON OF TEST RESULTS WITH PRESENT REGULATIONS

Existing regulations for fire protection for belt conveyors in underground coal mines were examined to determine if or how they differ from the results of the work described herein. The following summarizes that examination.

75.1101-1 Deluge-Type Water Spray Systems

Evaluation of water extinguishing systems in this program was limited to automatic sprinkler systems. Since the sprinkler heads in an automatic sprinkler system are individually actuated by heat, the protection afforded by deluge type systems actuated by a comparable means of detection is assumed to be as or more effective, provided water supplies are adequate.

(b) "... the spray application rate shall not be less than 0.25 gallon per minute per square foot of the top belt ..."

Most test fires were effectively controlled with a single overhead branch line of standard 1/2 inch orifice sprinklers at 10 psi (the minimum recommended operating pressure) when spaced on 10 foot centers. For the 30 inch belt width used in this test program, this results in a spray application rate of 0.72 gallon per minute per square foot of top belt surface. For a 60 inch belt width, the rate would be 0.36 gallon per minute per square foot of top belt surface.

(b') "... the discharge shall be directed at both the upper and bottom surfaces of the top belt and to the upper surface of the bottom belt."

This requirement flows from full scale trials conducted in the Bureau of Mines Experimental Mine as described on page 13 of RI 7053. In those trials the sprinkler heads were spaced 30 and more feet apart. Thus, the difference between those results and the results of the single overhead branch line in this test program is to be expected, and a single branch line above the belt should suffice provided the heads are standard 1/2 inch orifice at 10 or more psi and are spaced on 10 ft centers.

75.1101-3 Water Requirements

"... the water supply shall be adequate to provide flow for 10 minutes except that pressure tanks used as a source of water supply shall be of 1,000-gallon capacity for a fire-resistant belt and 3,000 gallons for a nonfire-resistant belt may be provided."

While controlled, the test fires were often not completely extinguished within 10 minutes. To guard against possible redevelopment of fire, an inspection of the fire zone should be required prior to cessation of water flow and the water supply should provide flow for at least 10 minutes.

75.1101-4 Branch Lines

"As a part of the deluge-type water spray system, two or more branch lines of nozzles shall be installed. The maximum distance between nozzles shall not exceed 8 feet."

As mentioned above, a single overhead branch line with sprinklers spaced on 10 ft centers was successful in controlling and extinguishing most test fires. However, should ventilation air flow rates exceed 250 fpm, then 8 ft spacings should be maintained.

75.1101-5 Installation of Foam Generator Systems

(d) "Water, power and chemicals required shall be adequate to maintain water or foam flow for no less than 25 minutes."

In the tests conducted with high-expansion foam, extinguishment of the belt fire was immediate upon envelopment by the foam which, per 75.1101-5 (b), must occur within 5 minutes.

75.1101-8 Water Sprinkler Systems; Arrangement of Sprinklers

(a) "At least one sprinkler shall be installed above each belt drive, belt take-up, electrical control, and gear-reducing unit, and individual sprinklers shall be installed at intervals of no more than 8 feet along conveyor branch lines."

(b) "Two or more branch lines, at least one of which shall be above the top belt and one between the top and bottom belt, shall be installed in each sprinkler system to provide a uniform discharge of water to the belt surface."

As discussed for the deluge type systems, a single branch line over the top belt, with a residual pressure of 10 psi, and with standard 1/2 inch orifice sprinklers spaced at intervals of 10 ft was found to be adequate, except where the average air velocity was 350 fpm. At this air speed the 10 ft spacing was adequate with a 212^{o}F sprinkler actuation temperature, but an 8 ft spacing was required with 280^{o}F sprinklers.

(c) "The water discharge rate from the sprinkler system shall not be less than 0.25 gallon per minute per square foot of the top belt and the discharge shall be directed at both the upper and bottom surfaces of the top belt and to the upper surface of the bottom belt. The supply of water shall be adequate to provide a constant flow of water for 10 minutes with all sprinkler functioning."

Comments on water flow rate and water supply requirements are given under 75.1101-1 (b) and 75.1101-3.

(d) "Each individual sprinkler shall be activated at a temperature of not less than 150°F, and not more than 300°F."

Actuation temperatures of 212°F and 280°F effectively controlled most test fires. As discussed under 75.1101-8, however, use of 280°F sprinklers required the sprinkler spacing interval to be limited to 8 feet.

Effective control also resulted with a 165°F actuation temperature, although more sprinklers than necessary were actuated.

75.1101-11 Inspection of Water Sprinkler Systems

"Each water sprinkler system shall be examined weekly and a functional test of the complete system shall be conducted at least once each year."

Where applicable, the inspection guidelines set forth in National Fire Protection Association 1973-74 edition, Code No. 13A, "Recommended Practice for the Care and Maintenance of Sprinkler Systems" should be followed.

75.1101-14 Installation of Dry Powder Chemical Systems

System installation should include a trial discharge and subsequent inspection to insure that powder has been distributed to all belt surfaces.

An additional requirement recommended for dry powder chemical systems is an immediate inspection of the belt head area after actuation of the system, to protect against reignition.

75.1101 General Comment Regarding Extent of Protection

The extent of coverage required for the above extinguishing systems is 50 feet for fire-resistant belt and 150 feet for nonfire-resistant belt. The effectiveness of the fire protection systems demonstrated in this test program, and the burning properties of the nonfire-resistant belt samples observed, tend to indicate that coverage of only 50 feet of nonfire-resistant belt would be adequate.

75.1103-4 Automatic Fire Sensors and Warning Device Systems; Installation; Minimum Requirements

(a)(1) "Where used, sensors responding to temperature rise at a point (point-type sensors) shall be located at or above the elevation of the top belt, and installed at the beginning and end of each belt flight, at the belt drive, and in increments along each belt flight so that the maximum distance between sensors does not exceed 125 feet, except as provided in subparagraph (3) of this paragraph (a)."

Point type sensors in the belt head area, used for automatic actuation of a belt head fire extinguishing system, should be spaced in accordance with the recommendations of UL, FM, or some other approved testing laboratory. Normally, this would be between 10 and 50 feet, according to the rating of the sensor used. Also, only those detectors located within the area of coverage of a suppression system should actuate that system. The response temperature range of point type sensors should also be that recommended by UL, i.e., where the maximum ambient temperature does not exceed 100°F, the detector rating should be between 135° and 165°F. For maximum ambient temperatures between 100°F and 150°F, the detector rating should be between 175°F and 225°F.

(a)(2) "Where used, sensors responding to radiation, smoke, gases, or other indications of fire, shall be spaced at regular intervals to provide protection equivalent to point type sensors, ..."

Line type temperature sensors should also be located at or above the elevation of the top belt, and should be no less sensitive than a 286°F automatic sprinkler.

The use of smoke and other product of combustion type detectors is not recommended for conveyor belt protection, due to the effects of dust. Where protection from dust can be provided, either by maintaining a relatively dust free environment or by effective periodic maintenance of the detectors, their spacing along belt flights should be no greater than 250 feet, or four times the average air velocity, whichever is greater.

The use of optical (UV and IR radiation) type detectors also are not recommended for protection of belt flights. If used for belt head fire detection, spacing should be at intervals not greater than 20 feet, and each detector's field of vision of the belt being protected should not be obstructed.

75.1103-6 Automatic Fire Sensors; Actuation of Fire Suppression Systems

"Automatic fire sensor and warning device systems may be used to actuate deluge-type water systems, foam generator systems, multipurpose dry-powder systems, or other equivalent automatic fire suppression systems."

Only detectors located within the area of coverage of the fire suppression system should actuate the system.

75.1103-10 Fire Suppression Systems; Additional Requirements

"Where the average air velocity along the belt haulage entry exceeds 100 feet per minute, or the belt is not fire resistant, or both, the fire suppression system in the belt haulageway shall conform with the following additional sensor and cache requirements:

(a) The maximum distance between sensors along the belt haulageway shall be 40 percent of those distances specified or established in accordance with paragraph 75.1103-4 (a)(1) or (2), as applicable, ..."

The test data does not indicate a need for more extensive sensor coverage for the above air velocity and belt conditions.

18.65 (Schedule 2G) Flame Test of Conveyor Belting and Hose

In a test closely approximating that of Schedule 2G, paragraph 18.65, a sample of new fire resistant PVC belting was tested and passed, i.e., the flame self-extinguished within the required time. When repeated without application of the specified 300 fpm air flow, however, the sample continued to burn until consumed. Full scale tests on this belting resulted in fires of greater intensity and which propagated faster than with new nonfire-resistant rubber belting, which did not pass the Schedule 2G test. This tends to suggest that the present Schedule 2G test may not be sufficiently representative of a full scale fire situation.

3. SUMMARY OF FINDINGS

The findings of this program primarily involve the burning properties of conveyor belting, the control of conveyor belt fires, and the effects of the coal mine environment on fire detection devices. Listed below is a summary of these findings.

1. New belt samples burned more readily than used samples of the same belt make.

2. With used neoprene belt, a sample with moisture in the carcass had essentially the same burning properites as a sample of the same belt that had been thoroughly dried.

3. Polyvinyl chloride belting burned most readily of the fire-resistant belt samples tested.

4. One of the new PVC belts burned more readily than the one new nonfire-resistant rubber belt tested.

5. Of a total of 12 conveyor belt samples tested, six sustained fire. They are, in the order of increasing flammability, used nonfire-resistant rubber (manufacturer unidentified), new Bridgestone fire-resistant rubber, new Goodyear fire-resistant rubber (these three were marginal in sustaining fire), new B. F. Goodrich Koroseal Nylock PVC (fire-resistant), new B. F. Goodrich Medium Longlife nonfire-resistant rubber, and new Scandura Gold Line PVC (fire-resistant).

6. Preheating contributed most significantly to belt ignition, coating the belt surface with mineral oil contributed slightly, and introduction of coal dust tended to retard ignition, due apparently to its initial insulating effect.

7. Relatively consistent results were obtained in repeat trials of the test fire when conducted under the same conditions.

8. Decking between the conveyor belt layers slowed the development of the test fire significantly and resulted in less intense belt fires.

9. Increase in air velocity tended to retard ignition, but then to increase the rate of propagation once ignition had been established.

10. The maximum rate of flame spread, obtained on new Scandura PVC belting at 350 fpm air flow, was 6 feet per minute. The rate of flame spread on this belt in neutral air was 0.7 feet per minute.

11. Test condition changes appearing to have little adverse effect on the effectiveness of the fire protection systems tested were increasing the air velocity, decreasing the roof clearance, and placement of a deck between the conveyor belt layers.

12. With automatic sprinkler systems, spacing of heads was the variable having the greatest influence on system performance.

13. Actuation of no more than two sprinkler heads was required for successful control and extinguishment of belt fires.

14. Sprinkler heads with a temperature rating of 165°F resulted in actuation of more sprinklers than were necessary for fire control.

15. Variation in residual pressure of automatic sprinkler systems resulted in a relatively small change in fire control effectiveness.

16. The reaction times of automatic sprinklers with actuation temperatures of 212°F and 280°F were comparable to the reaction times of fire sensor devices at UL and FM recommended spacings.

17. Thermal type sensors were found most suitable for mine use, with line types being generally more sensitive than point types due to their providing continuous coverage.

18. Most smoke and products of combustion type sensors malfunctioned when exposed to dust and water spray.

19. The range of optical (UV and IR) type sensors was found to be relatively short for conveyor belt applications. Most of these types detectors were also sensitive to alien light, especially electric arcing, and were obscured by dust accumulations over a period of time.

20. The possibility of reignition of a conveyor belt fire was found to be greater with dry chemical extinguishing than with water or high expansion foam.

4. TEST FACILITY

Testing on contract H0122086 was conducted at a site located in Rockaway Township, New Jersey. The site consisted of a twin test gallery, a mobile van providing space for an office and an instrumentation room, and a nearby heated storage building.

The galleries consisted of two side-by-side, above-ground, simulated belt haulageways, each six feet high by 15 feet wide by 175 feet long. Each was equipped with two ventilation fans capable of producing air flows of 125 and 300 fpm, and a combined air flow of 350 fpm. Figures 1 and 2 show the configuration of the test gallery.

The galleries were constructed of galvanized metal with external wood support members to minimize fire damage. The roofs had a six inch pitch for water run off. Access doors and viewing windows were provided in the gallery sides at convenient locations. The base of the gallery was blacktop, except for a 35 foot section under the conveyor head piece and take-up assembly, which was concrete.

The conveyors were positioned three feet from the inside rib and with the discharge pulley 30 feet downwind from the ventilation fans. The conveyor was a floor-mounted type supported by wire rope, and extended for 125 feet, including the head piece and take-up. The top belt layer in the take-up assembly was approximately three feet below the roof. Most of the belt fires were ignited on the second belt layer in the take-up assembly.

For the evaluation tests, 1 by 3 inch boards were positioned on the gallery roof at three foot intervals, to provide an indication of flame spread and to serve as one of the criteria for successful extinguishment. If three or more boards burned, the extinguishment was considered not successful.

Instrumentation consisted of recording of temperatures at selected points in the test galleries, and monitoring the actuation of the various detection devices during the evaluation tests. For temperature monitoring, 12 chromel-alumel type thermocouples were placed in each gallery and monitored by a Bureau-furnished, 12 point temperature recorder. The recorder was configured to monitor temperatures from 0 to 1000°F. Two of the thermocouples were placed on the preheat plate to monitor the preheat temperatures, and the remainder were positioned at various points on the gallery roof to provide a temperature profile for each test. In some of the preliminary tests on belt types resulting in flame propagation, one thermocouple was attached near the end of the belt sample, to indicate when the fire had propagated to this point.

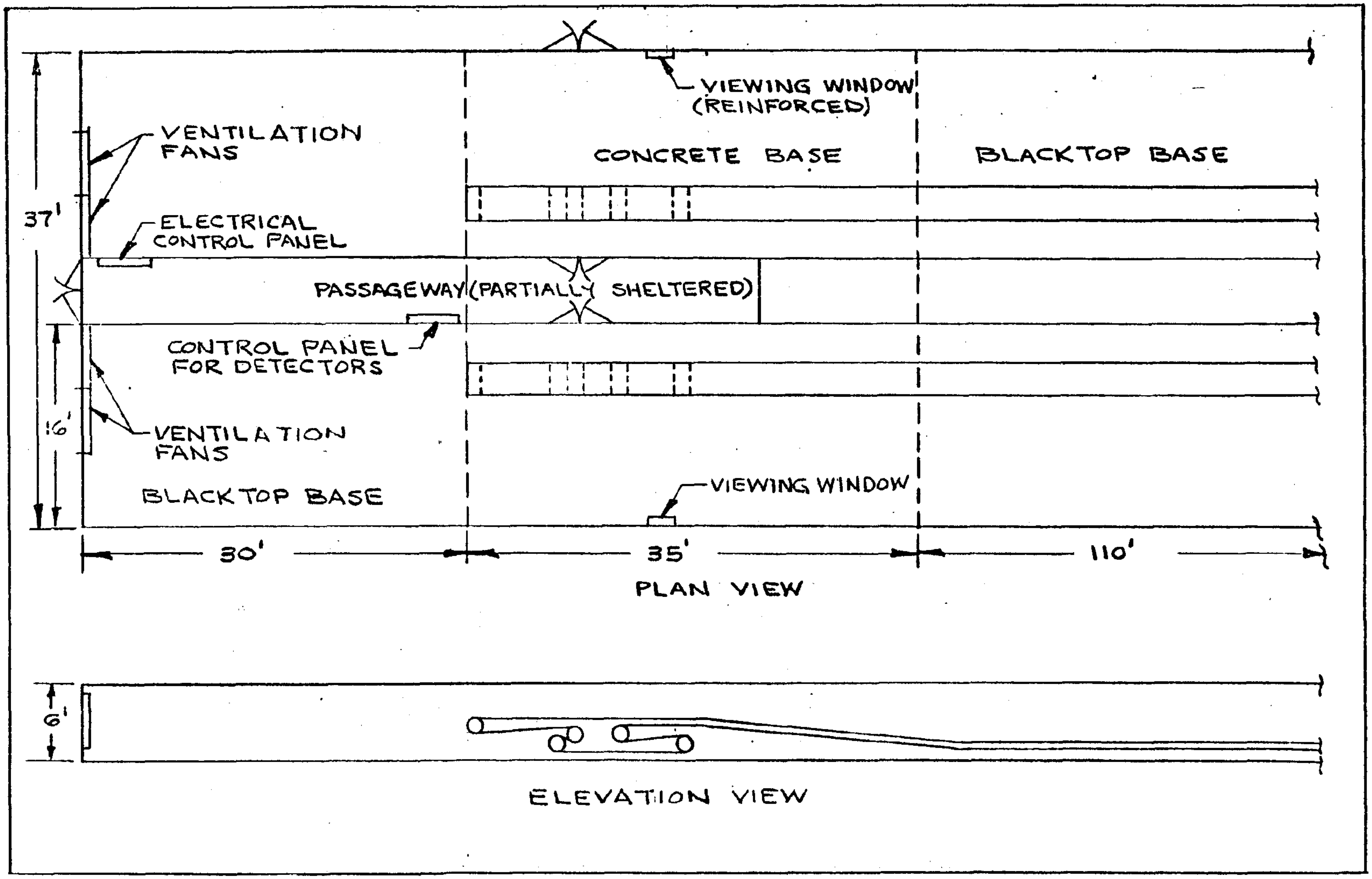

Figure 1
Test Galleries

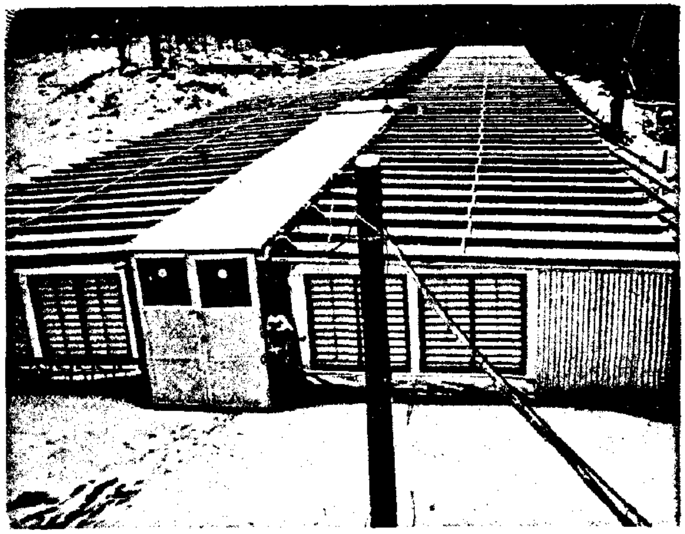

Figure 2

Front View of Test Galleries

Actuations of the detector devices were monitored by means of two ten channel event recorders. A reference marker was used to denote the time of ignition so that actuation times could be determined. Both the temperature and the detector event recorders were located in a mobile van which served as a combination office and instrumentation room. (See Figure 3.)

Measurement of the ventilation air flow was made with an Alnor Instrument Co. Velometer Jr. hand held velometer. Measurements were taken periodically throughout the test program at various locations in the galleries. The variation in air flow in the area where the tests were conducted was approximately ± 20%.

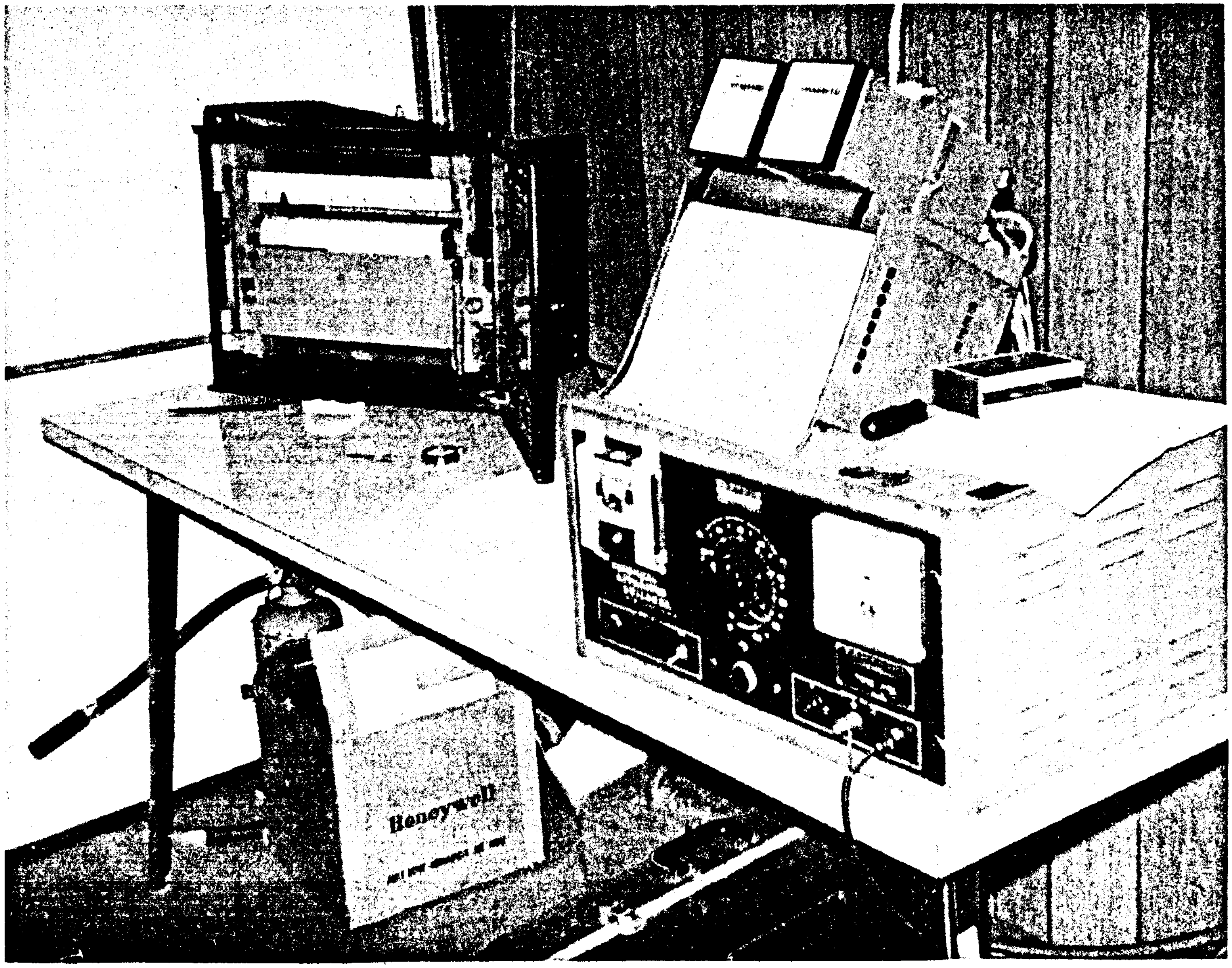

Figure 3

Instrumentation room, showing 12 point temperature recorder (left) and multipoint event recorders (upper right), used for recording the actuation of detection devices.

5. PRELIMINARY TESTING

A number of preliminary tests were conducted in order to establish suitable parameters and methods for conducting the evaluation tests. The primary objective of these preliminary tests was to establish a self-sustaining fire involving USBM approved fire resistant conveyor belting. The two areas receiving the most attention in this group of tests were (1) the method of ignition and (2) the specific types and makes of conveyor belts used.

5.1 METHOD OF IGNITION

Ignition was first attempted with a 2000 watt electric heating element shaped to apply the heat uniformly over a one foot square area of belt surface. Tests were made with both fire-resistant and nonfire-resistant rubber belting.

Ignition on the fire resistant samples was achieved in 10 to 15 minutes, however no propagation occurred, and the fires usually self-extinguished after power was removed from the element. With the nonfire-resistant belt, ignition was achieved in approximately five minutes and a self-sustaining fire did result, although propagation was insignificant. The heating elements exhibited a fairly short life, burning out after only two or three tests, due to the high localized heat generated by contact with the belt surface.

Trials were then made with propane gas burners to achieve more rapid ignition and to avoid heating element failures. A burner of the type commonly used in hot water heaters was used, and produced ignition usually in under 5 minutes. Tests were conducted with single layers of used fire-resistant rubber and PVC, and nonfire-resistant rubber belting. Again, fire could be sustained on only the nonfire-resistant rubber belting.

The next step was to preheat a 30 inch square of belting from underneath by placing a 1/4 inch steel plate between the propane burner and the belt surface. The burner was adjusted to preheat the 30 inch belt section to approximately 450°F. The plate was then pulled out, allowing the burner to impinge directly on the preheated belt surface. When applied to nonfire-resistant rubber belting, a more intense fire resulted than in previous tests without preheating, but the intensity decreased after the preheated section was consumed. Additional tests were conducted with 1/4 inch steel and 1/2 inch aluminum plates 5 feet long by 30 inches wide, using 2 and 3 propane burners, with other belt types, with coatings of coal dust, grease and/or mineral oil on the plate and the upper surface of the conveyor belt, and by igniting the top surface of the preheated belt surface with a large propane torch.

Various combinations of coal dust, grease and mineral oil were applied to the belt surface, and seemed to have little effect on the development of the test fire. Two types of coal dust were used, one with a volatile content of 23%, and one with 37%, both of which were ground to a particle size of 50% less than 74 microns. The grease was No. 2 multi-purpose, and the mineral oil was a standard commercial grade.

A coating of mineral oil on the belt surface appeared to result in a more intense fire than did the application of the other two materials or combinations thereof. In some tests, the coal dust seemed to retard the development of the fire, apparently due to its momentarily shielding the belt from the heat from the ignition torch. A summary of each of the preliminary tests, starting with those using the preheat plate and propane gas as an ignition source, is provided in Appendix A.

The method of ignition used for the evaluation tests consisted of a 15 minute preheat using the 5 foot long by 30 inch wide by 1/2 inch thick aluminum plate heated by two propane gas burners. The gas pressure was adjusted as necessary to achieve a temperature of approximately 500°F between the plate and the belt surface, which required a heat release rate of approximately 8,000 Btu/min. This temperature was measured by two thermocouples, one at the center of the plate over one of the burners, and the other at the edge of the plate. The preheat temperature was considered to be the average of the two thermocouples.

Ignition was achieved by applying a propane torch to the top surface of the preheated belt section. The torch liberated heat at a rate of approximately 3,500 Btu/min, and produced a flame approximately 3 inches in diameter by nine inches long. (The total heat input to the ignition zone was 11,500 Btu/min.) The point of ignition was on the return belt in the take-up section. (See Figure 4.) Twenty foot test sections were spliced into the load bearing and return belts and were changed for each test. This minimized the amount of belt consumed in each test, and also simplified replacement of belt for the next test. The first 12.5 feet of both test sections were coated with mineral oil. The conveyor belting was also clamped to the take-up pulley to prevent the belt from falling away from the point of ignition after it had burned through and separated. The gas burners and torch were turned off after the fire had become obviously self-sustaining and the propane gas was no longer a contributing factor to the fire. Application of the ventilation air flow was withheld until one minute after turn-on of the ignition torch, so as to allow more rapid ignition of the belt test section.

5.2 CONVEYOR BELT SELECTION

The objective of the preliminary test phase was to select a belt and method of ignition that would produce a test fire suitable for evaluating fire protection

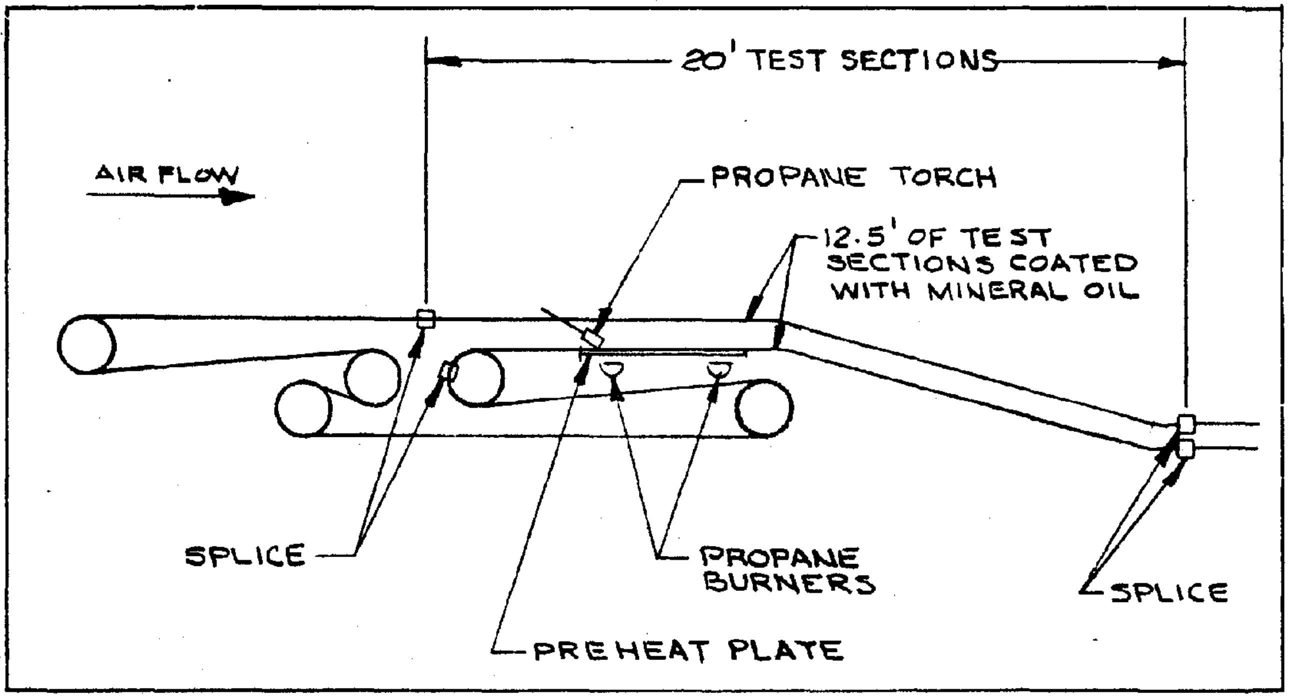

Figure 4

Method of Ignition

equipment. It was not intended to be a comparative evaluation, and therefore did not include all the various types and makes of conveyor belts used in coal mines.

A total of 40 full scale preliminary fire tests, as listed in Appendix A, were conducted on a total of 12 different conveyor belts. These included both new and used belting, and covering materials of fire-resistant rubber, neoprene and polyvinyl chloride (PVC), and nonfire-resistant rubber. The fire-resistant belts conform to USBM Schedule 2G. The belts tested are listed in Table I.

A self-sustaining fire was achieved on the following six belts, using the various ignition methods discussed. (Not all ignition methods were used on all belts.)

FR-1	R-2	PVC-1
FR-2	R-3	PVC-3

TABLE I

CONVEYOR BELTS TESTED

Designation	Belt Identification	Belt Thickness
	Fire-Resistant Rubber	
R-1	Used, Republic Rubber, 5 ply	5/16 inch
R-2	[a]New (SBR), Bridgestone, Nycon, 3 ply	
R-3	New (SBR), Goodyear, Glide 220, 2 ply	
	Fire-Resistant Neoprene	
N-1	Used, B. F. Goodrich, Caricoal, 5 ply	7/16
N-2	Used, Acme Hamilton, Pyroprene, 5 ply	3/8
	Fire-Resistant PVC	
PVC-1	New, B. F. Goodrich, Koroseal Nylock, Solid Weave	1/4
PVC-2	Used, B. F. Goodrich, Koroseal Nylock, Solid Weave	1/4
PVC-3	New, Scandura, Gold Line, Solid Weave	5/16
PVC-4	Used, Scandura, Gold Line, Solid Weave	1/4
PVC-5	Used, Hewitt Robbins, Solid Weave	1/4
	Nonfire-Resistant Rubber	
FR-1	Used, Manufacturer Unidentified, 5 ply	3/8
FR-2	New, B. F. Goodrich, Medium Longlife, 2 ply	5/16

[a] The R-2 belting was 20 inches in width. All others were 30 inches wide.

Of the 12 belts tested, the new belts tended to burn more readily than the used, which tends to contradict previous investigations on belt flammability.[4] Self-sustaining fires were achieved on five new belts, but on only one used belt, that one being a nonfire-resistant rubber sample. It should be noted, however, that on the non-PVC used belting the samples were all 5 ply, ranging in thickness from 3/8 to 7/16 inch, whereas the new samples were either 2 or 3 ply, 5/16 inch thick. With the PVC belting, the used samples were the same and in one case, of a lesser thickness than the new samples.

Of the five new belts that sustained fire, PVC-3 resulted in the highest gallery surface temperatures and the highest rate of propagation, and was therefore selected as one of two belts used in the evaluation test fires. The other belt used was new nonfire-resistant rubber, FR-2, to provide a comparison with multi-ply non-PVC type belt.

Following is a discussion of the burning characteristics observed with each of the belt types:

5.2.1 Rubber (Nonfire-Resistant)

In Test No. 1 with used belting (FR-1), a self-sustaining fire was achieved by preheating a 30 inch section of belt prior to ignition. There was very little propagation beyond the preheated section, however, and the flame intensity had decreased to a very low level when the test was terminated at 18 minutes. The belt sample was obtained from a used equipment dealer, and data on its age and usage was not available.

The tests involving the new non-fire resistant rubber belting were conducted by preheating a five foot section of belt, and resulted in propagation of the flame to the ends of the 20 foot test sections within 14 minutes in one test, and in 10.5 minutes in another. The two tests were conducted with and without mineral oil on the belt surface, respectively, and resulted in roof temperatures in excess of 1000°F in both. The belting produced a suitable fire for the evaluation tests, and was one of the two belts used for the evaluation tests.

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[4] Maas, W. "Fire Hazards Due to Slipping Rubber Belt Conveyors", Geologie en Mijnbouw (The Netherlands), 11e Jaargang No. 11, Nov. 1949, pp. 309-312.

5.2.2 Rubber (Fire-Resistant)

Test No. 5 was conducted with used 5 ply fire-resistant rubber belting by preheating a 30 inch belt section prior to ignition. The fire did not propagate beyond the point of ignition, and burned out after 23 minutes.

Although self-sustaining fires were generated on the two new fire-resistant rubber (SBR) belt makes (R-2 and R-3), the flame propagation was slow. A propagation rate of 8 feet in 19 minutes was achieved with R-2, and 10 feet in 17 minutes on R-3. The flame intensity was relatively low with both makes, and both were involved in other tests where the fire died out before reaching the end of the test sections. Belt R-2 was only 20 inches wide, whereas all other belts tested were 30 inches wide.

5.2.3 Neoprene (Fire-Resistant)

A total of four tests were conducted on used samples of neoprene conveyor belting. All required several minutes to achieve ignition, and resulted in fires of low intensity which eventually died out or were in the process of doing so when the tests were terminated. Belt N-2, having been stored outside, had moisture in the carcass, and produced steam when subjected to preheat and ignition. A sample of this belt was therefore dried at elevated temperatures for 70 hours and retested, with essentially the same results as with the moist sample. One of the tests was also conducted with a grease/coal dust mixture coating on a five foot section of the belt surface. This resulted in a more intense fire as the grease/coal dust coating burned, but then died down and was nearly out when the test was terminated at 32 minutes. This fire did not propagate beyond the coated section.

5.2.4 PVC (Fire-Resistant)

A total of 28 preliminary tests were conducted with PVC belting, seven of which were with used belt samples and 21 with new belt samples. A self-sustaining fire was not produced in any of the seven tests with used belting. In most of these tests, the fire was limited to the preheated section which, in some cases, was coated with coal dust or mineral oil. In test No. 15, fairly high gallery temperatures were produced by igniting the bottom (4th) belt layer in the take-up, thereby involving four belt layers in the fire. The fire burned its way to the top layer and then died down to a low intensity. Nine feet of the top belt layer had burned when the test was terminated 15 minutes after ignition.

In another test (No. 16) on a new PVC belt sample, the fire propagated to the end of the new sample, and continued along 40 feet of adjacent used PVC belt at a propagation rate of approximately one foot per minute (see Figure 5). The fire was extinguished 55 minutes after ignition. Apparently the fire on the new PVC sample generated enough heat to create a self-sustaining fire on the used PVC belt.

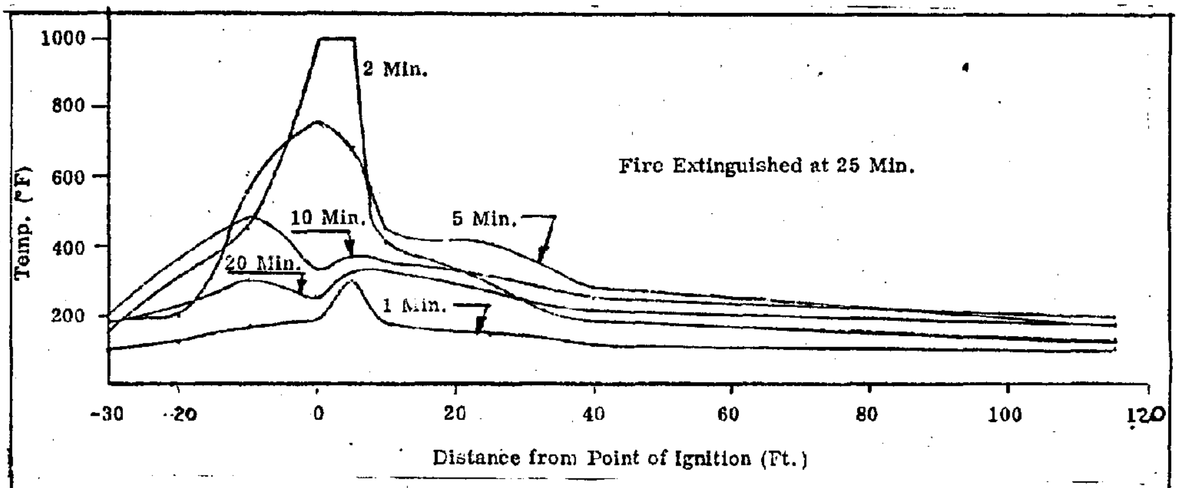
Flame propagation occurred on all of eleven preliminary tests on the PVC-3 belt, and on five of ten tests on the PVC-1 belt. The PVC-3 produced fires of greater intensity and higher rates of propagation than PVC-1. In tests with PVC-3 involving mineral oil and a five foot preheated section of belt, the fire propagated to the ends of the 20 foot test section in as little as four minutes after ignition with a 125 fpm air flow, and within three minutes on a test with 350 fpm air flow. Figure 6 shows the temperature profiles at various times for PVC-3 belt tests at neutral, 125 fpm, and 350 fpm air flows. Gallery roof temperatures in most of the PVC-3 tests exceeded 1000°F, which was the upper limit of the temperature recorder.

With PVC-1, the maximum gallery roof temperatures ranged between 400 and 800°F. The maximum roof temperatures in all the new PVC tests occurred during burning of the preheated belt section, and then the temperature usually decreased as the fire moved along to the non-preheated areas. In some of the tests with PVC-3, however, the rapid propagation made extinguishment necessary while the fire was at maximum intensity, to prevent propagation beyond the test sample. PVC-3 produced the most intense fire of all the belts tested, and was one of the two belts used for the evaluation test fires.

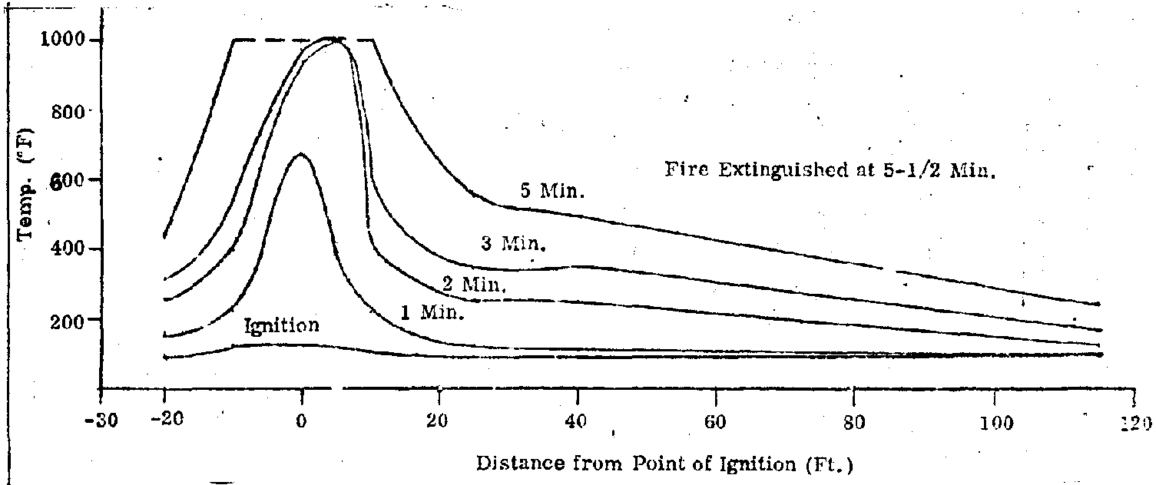
A series of six tests (Nos. 31 thru 36) were conducted to check repeatability of the test fire with the PVC-3 belt. The results of all six were relatively similar, except for one (No. 34) which was conducted during rainy weather. The gallery floor was extremely wet at the point where the burning belt fell to the floor after separation, causing the burning rate to slow down until the fire had progressed past this point.

Figure 5

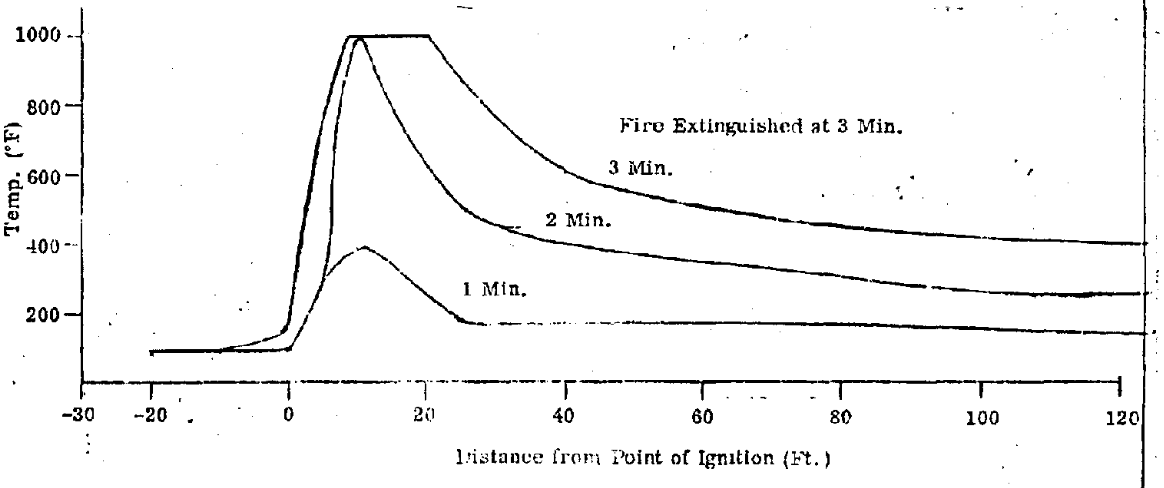
Test gallery interior following test No. 16 in which 60 ft of conveyor belting burned. View is down wind, with a portion of the take-up mechanism shown at the lower left. The light colored bar holds the 30 x 60 x 1/2 inch aluminum preheat plate in place.



Test No. 37 (Neutral Air Flow)



Test No. 33 (125 fpm Air Flow)



Test No. 38 (350 fpm Air Flow)

Figure 6
Temperature Profiles

6. EXTINGUISHING

A total of 76 evaluation tests were conducted on three basic fire extinguishing types, 56 with automatic sprinklers, 9 with high expansion foam, and 11 with ABC powder.

6.1 TEST FIRE

A "standard" test fire was established, based on the results of the preliminary tests and the test variables specified in the contract statement of work. Identification of one set of test conditions as "standard" serves as a reference point and enables easy identification of test fires with conditions varying from the "standard". This method of identification is employed in Appendix B which provides a summary of all the evaluation tests conducted. The test conditions are identified as "standard" or by listing those variables which differ from the "standard" test conditions.

Table II lists the test condition variables. As previously mentioned, the belt test sections were 20 feet long and were spliced into the two top belt layers as illustrated in Figure 4. New test sections were installed for each test.

The air flow rates were achieved by using one or both of the two ventilation fans. The 125 fpm rate was produced by the low speed fan, and 350 fpm was achieved by adding the higher speed fan. For neutral air flow, both fans were off, with air movement, if any, in the test gallery being controlled by the wind conditions on the day of the test.

TABLE II

TEST CONDITIONS

Variable	Standard Conditions	Alternate Conditions
Conveyor Belt	PVC-3 (New)	New non-fire resistant rubber, FR-2
Air Flow	125 fpm	Neutral and 350 fpm
Deck Configuration	Without deck	With deck
Roof Clearance	3 ft above top belt	1.5 ft above top belt

For tests calling for a conveyor deck, 1/4 inch steel plates were placed between the two belt test sections. The roof clearance of 1.5 ft., measured at the ignition point, was achieved by elevating the conveyor 1.5 ft. off the gallery floor.

6.2 AUTOMATIC SPRINKLERS

Appendix B-I provides a summary listing of the 55 evaluation tests conducted with automatic sprinklers. These tests were conducted with various combinations of the test conditions listed in Table II, and with three additional variables in the sprinkler system configuration, these being actuation temperature, spacing and water pressure.

The sprinkler system for each gallery consisted of a two inch main at the roof, with 1/2 inch fittings at five foot intervals. Half inch branches were then used to achieve the desired spacings, with the sprinkler heads positioned at the roof and centered over the conveyor belt. Spacings of 8, 10, 12 and 15 feet were tested. The sprinklers were positioned with the ignition point equidistant between the first two, except for the 15 foot spacings when the first sprinkler was placed 5 feet upwind of the ignition point. Sufficient sprinklers were installed in each test to cover the entire 20 foot belt test section.

Pressure was regulated manually by a gauge and hand valve located outside the gallery. Constant pressure was maintained for each test by adjusting the hand valve as each additional sprinkler actuated. Since two inch mains were used, the pressure drop between the regulator valve and the sprinkler heads was considered insignificant. Tests were conducted at regulated pressures of 10, 20, 30 and 50 psi.

The sprinkler heads were Starguard Model E and Globe Model G, and were standard half inch orifice pendant types with fusible link type actuation. Tests were conducted with actuation temperatures of 165, 212 and 280°F. (Initially, 286°F sprinklers were used; however, the 280°F units were more readily available locally and were used on subsequent tests.)

Table III provides a summary, in chart form, of the automatic sprinkler test results. The criteria for effective detection and extinguishment were (1) prevention of the fire on the conveyor belt from igniting three or more of the 1" by 3" softwood boards placed on the ceiling at three foot intervals, and (2) prevention of the last downwind sprinkler from being actuated. As can be seen from Table B-I (Appendix B), most of the test fires were contained by the actuation of one or two sprinklers, and sprinkler configurations determined to be inadequate were usually so judged due to charring of three or more softwood boards, and seldom due to actuation of the last downwind sprinkler.

TABLE III

SUMMARY OF DATA - AUTOMATIC SPRINKLERS

Test Condition	Actuation Temp. (°F)	Residual Pressure (psi)	Spacing			
			8'	10'	12'	15'
Standard (See Note 6)	286	50		✓		x
		30			✓	
		20		✓	✓	
		10	✓	✓	3	
Standard	212	20			✓	✓
		10		✓	x	
Standard	165	20		✓		
		10	✓	x4	x4	
With deck	286	10		✓		✓
1.5 Ft. Roof Clearance	280	30			x	
		10		✓	x	
1.5 Ft. Roof Clearance	212	50			x	
		10		✓	x	
1.5 Ft. Roof Clearance	165	50		x		
		10	✓			
Neutral Air	280	10		✓	✓	x
350 fpm Air	280	50		x		
		10	✓	x		
350 fpm Air	212	> 10				5
		10		✓	✓	5
Non-fire Resistant Belt	280	10		✓	✓	✓
Non-fire Resistant Belt	212	10				✓
Non-fire Resist. Belt, Deck	280	10		✓	x	x
Non-fire Resist. Belt, 350 fpm Air	280	10			✓	x
350 fpm Air Deck	280	10		✓	✓	x
Non-fire Resist. belt, Deck 350 fpm	280	20			x	
		10		✓	x	

Notes

1. ✓ = Pass, x = Fail

2. Unless otherwise noted, all fail results were due to 3 or more 1" x 3" boards charred.

3. This combination failed with 212°F heads. Assumed to fail with 286° heads also.

4. Failure due to last down-wind sprinkler being actuated.

5. This test condition assumed to fail, based on results of previous tests.

6. "Standard" test condition consists of PVC-3 belting, 3 ft. roof clearance over the top belt, no deck on the conveyor, and 125 fpm air flow. These conditions apply unless otherwise noted.

As seen from Table III, not all of the combinations of sprinkler configurations were tested. Once the threshold point for successful extinguishment was determined for a given configuration variable, the testing moved on to another set of parameters. For example, only four tests were conducted with "standard" test conditions and a 212°F actuation temperature. At 10 psi residual pressure, successful extinguishment was achieved with 10 foot sprinkler spacings, but not with 12 foot spacings. The threshold for successful extinguishment is, therefore, 10 feet. Moving along to 20 psi residual pressure, it is assumed that the 10 foot spacing would be successful, since it was successful at 10 psi. Thus, the 12 foot spacing was tested and was successful, as was the 15 foot spacing. It can now be assumed that 15 foot spacings with the higher residual pressures would also result in successful extinguishment.

Most test fires were successfuly extinguished with the sprinklers on 10 foot centers, with 10 psi residual pressure, and with either 212°F or 280°F actuation temperatures. Figures 7 thru 12 are photos taken during test Nos. 112 and 113 with such a sprinkler system using 280°F sprinklers and at 350 fpm air flow.

Following is a discussion of the effects of the different test variables on the test results.

6.2.1 Spacing

Spacing appears to be one of the more critical of the sprinkler configuration variables, with successful extinguishment being indicated in all but four configurations with 10 foot spacings, but in less than half with 12 foot spacings. The four unsuccessful configurations with 10 foot spacings were successful at 8 feet.

6.2.2 Residual Pressure

Residual pressure does not appear to be critical in determining successful vs. unsuccessful extinguishment. In most configurations where successful extinguishment was achieved or indicated at 50 psi, it was also achieved or indicated at 30, 20 and in many cases, 10 psi. For this reason, variation in residual pressure was kept to a minimum in the latter part of the automatic sprinkler series, with most tests being conducted at 10 psi.

6.2.3 Sprinkler Actuation Temperature

With sprinkler actuation temperatures of 280°F and 212°F, only those sprinklers in close proximity of the belt fire were actuated. With 165°F sprinklers, however, all four sprinklers involved in the test were actuated on two occasions (tests 51 and

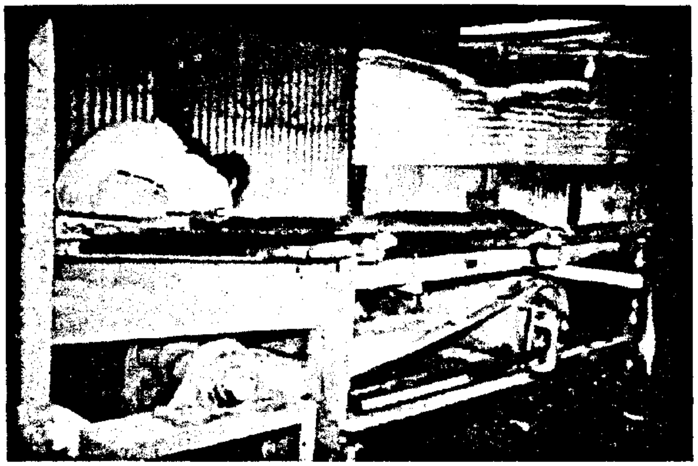


Figure 7

Test Setup for Automatic Sprinklers (Test No. 112)

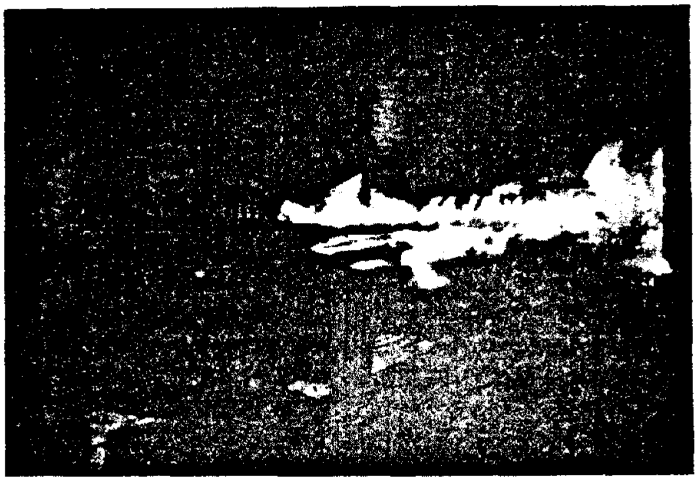


Figure 8

Test Fire at Approximately One Minute

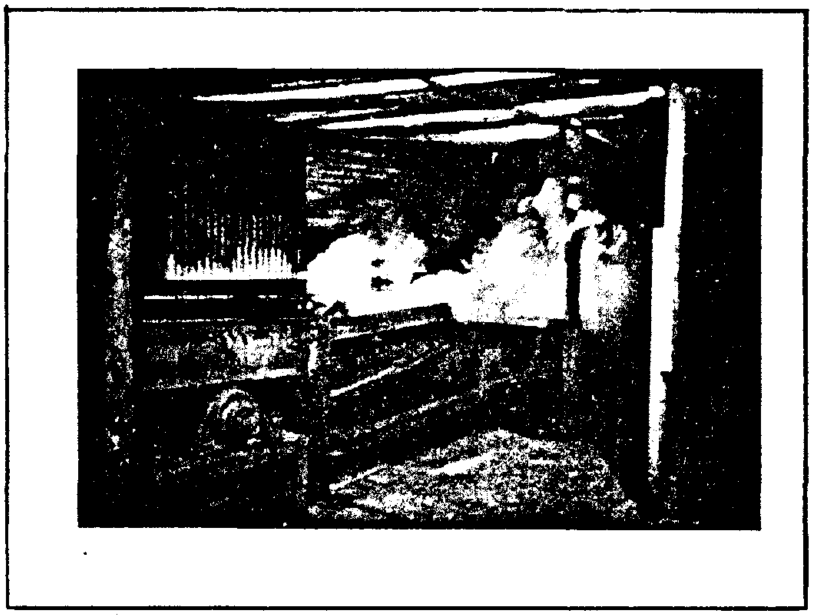


Figure 9

Test Fire Just Prior to Sprinkler Actuation

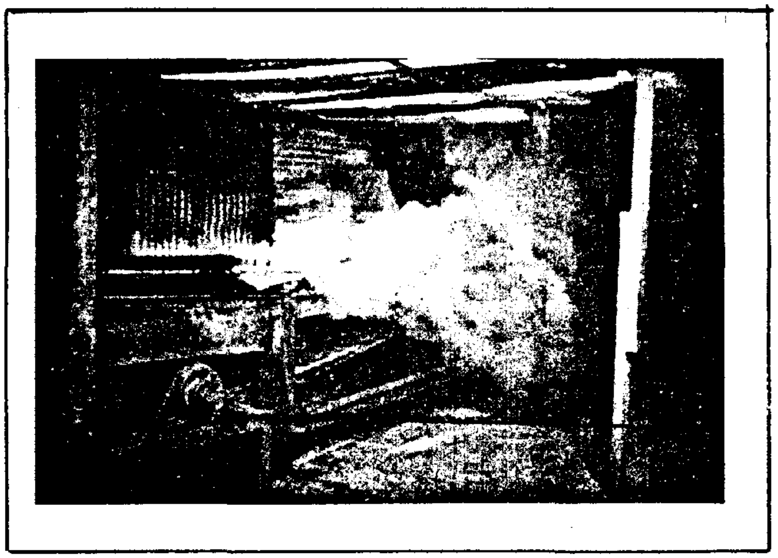


Figure 10

Test Fire at the Time of Sprinkler Actuation (2 min.)

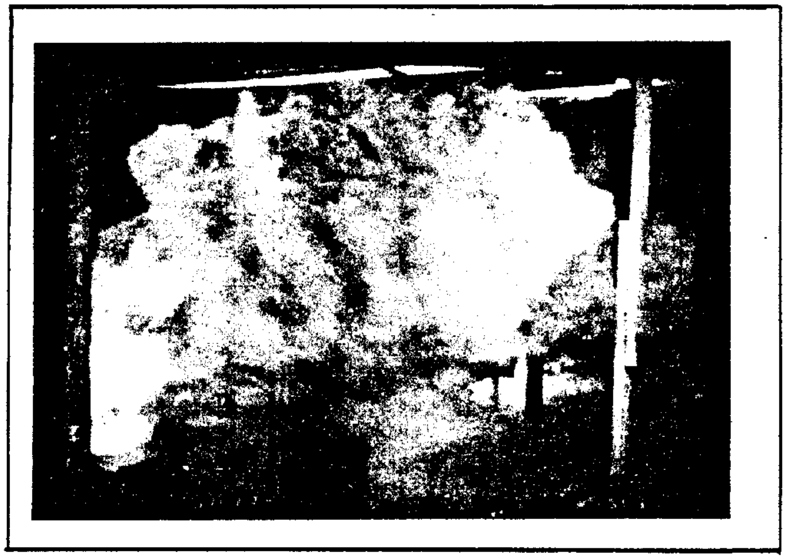


Figure 11

Action of Automatic Sprinkler

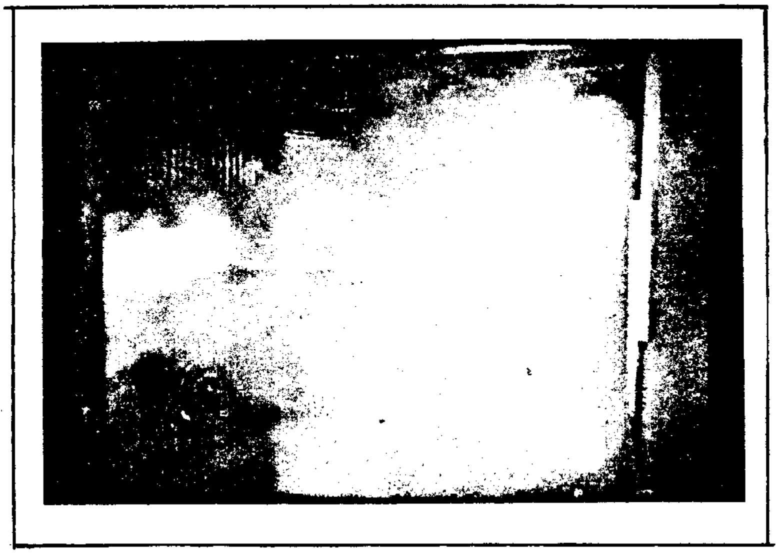


Figure 12

Belt Fire Nearly Extinguished

Figure 13

53), even though the belt fire was confined to the area between the first two sprinklers. This tends to indicate that the use of 165°F sprinklers could result in actuation of more sprinklers than are necessary to successfully contain and extinguish the fire, and would have a greater tendency to overtax a limited water supply. The 280°F and 212°F actuation temperatures provided similar test results, except in the case of the 350 fpm ventilation air flow. Here, the 212°F sprinklers were more effective. It appeared that actuation of the 280°F sprinklers were delayed slightly, due to the cooling effect of the higher air flow, allowing the belt fire to develop and propagate further before being extinguished.

6.2.4 Decking

A pilot test (No. 55) was conducted with metal plates, simulating a deck, placed between the two belt layers. The intensity of the resulting fire was significantly reduced. The point of ignition is on the top surface of the return belt, so that the effect of the deck is to shield the top belt from heat and flames. The top belt does ignite, although not as quickly as without a deck, and burns with less intensity than without a deck. As demonstrated in test No. 57, the fire, with a deck, was successfully contained and extinguished with minimum water pressure and maximum spacing (10 psi and 15 feet), and with the highest temperature sprinkler being tested (286°F). The deck does tend to shield the flames on the return belt from the water from the sprinklers. On the other hand, the cooling effect of the sprinklers seems to suppress the fire, causing it to eventually die out.

6.2.5 Roof Clearance

The effectiveness of water sprinklers appears to be slightly reduced by the lower roof clearance, as indicated by tests with 280°F and 212°F sprinklers. Tests in which 12 foot sprinkler spacings resulted in successful extinguishment with the 3 foot roof clearance, required 10 foot spacings to be successful with a 1.5 foot clearance. In other tests, however, 10 foot spacings were required for successful extinguishment for both the 3 foot and the 1.5 foot clearance. The water spray pattern is slightly reduced at the 1.5 foot clearance, and may be a factor in the results obtained.

6.2.6 Ventilation Air Flow

Three tests were conducted with neutral air flow and indicated that suppression was easier than at 125 fpm air flow, since successful extinguishment at 10 psi residual pressure and with 280°F heads was achieved with 12 foot sprinkler spacings with neutral air flow, but required 10 foot spacings at 125 fpm. With 350 fpm air flow, 8 foot spacings were required for successful extinguishment, thus indicating that the effectiveness of automatic sprinklers may decrease as the air velocity is increased. Just the opposite was observed with 212°F sprinklers, however, where successful extinguishment required 10 foot spacings with 125 fpm air flow, but only 12 foot spacings with 350 fpm air flow. The sprinkler actuation times were generally longer for all tests with 350 fpm air flow, apparently due to the cooling effect of the higher air flow on the heat sensitive sprinkler heads, which resulted in greater propagation of the belt fire prior to sprinkler actuation.

6.2.7 Conveyor Belt Type

As previously discussed, nonfire-resistant new rubber belt, FR-2, produced a less intense test fire than the new fire-resistant PVC-3. Consequently, the fires with the nonfire-resistant belt were easier to control and extinguish. All tests with this belt were successfully extinguished with sprinkler spacings of 10 feet or higher, whereas some of the same tests with the PVC belt required 8 foot spacings for successful extinguishment.

6.3 HIGH EXPANSION FOAM

The results of the nine tests with high expansion foam are listed in Table B-II (Appendix B). The criteria for successful extinguishment in this test series was the same softwood board criteria used for automatic sprinklers, i.e., ignition of three or more 1 x 3 inch softwood boards placed overhead at three foot intervals constituted unsuccessful extinguishment of the belt fire.

The foam generator used was a Kidde Hi-Ex 5000 cfm portable unit which produced foam with an expansion ratio of approximately 1000 to 1 and a stability of not more than 25% drainage in 25 minutes. The only foam parameter varied was the generation rate which, at 5000 cfm, was capable of enveloping approximately 50 feet of test gallery in one minute. In order to hold the expansion ratio constant at 1000 to 1, the generator was operated at the 5000 cfm rated capacity with the excess foam being discharged outside the test gallery by means of a specially fabricated discharge chute. (See Figures 14 and 15.) The chute had two discharge vents, one into the gallery and one overboard, both of which were fitted with zippers to control their openings and consequently the rate of foam being discharged into the gallery. Several tests were conducted without a belt fire to establish the zipper settings for various foam discharge rates.

The actuation time for the foam system was set at two minutes for most of the tests, this being a reasonable time within which a detection system should actuate for successful extinguishment. With the decked conveyor configuration, which slows down the development of the test fire, the foam system actuation time was set at 12.5 minutes.

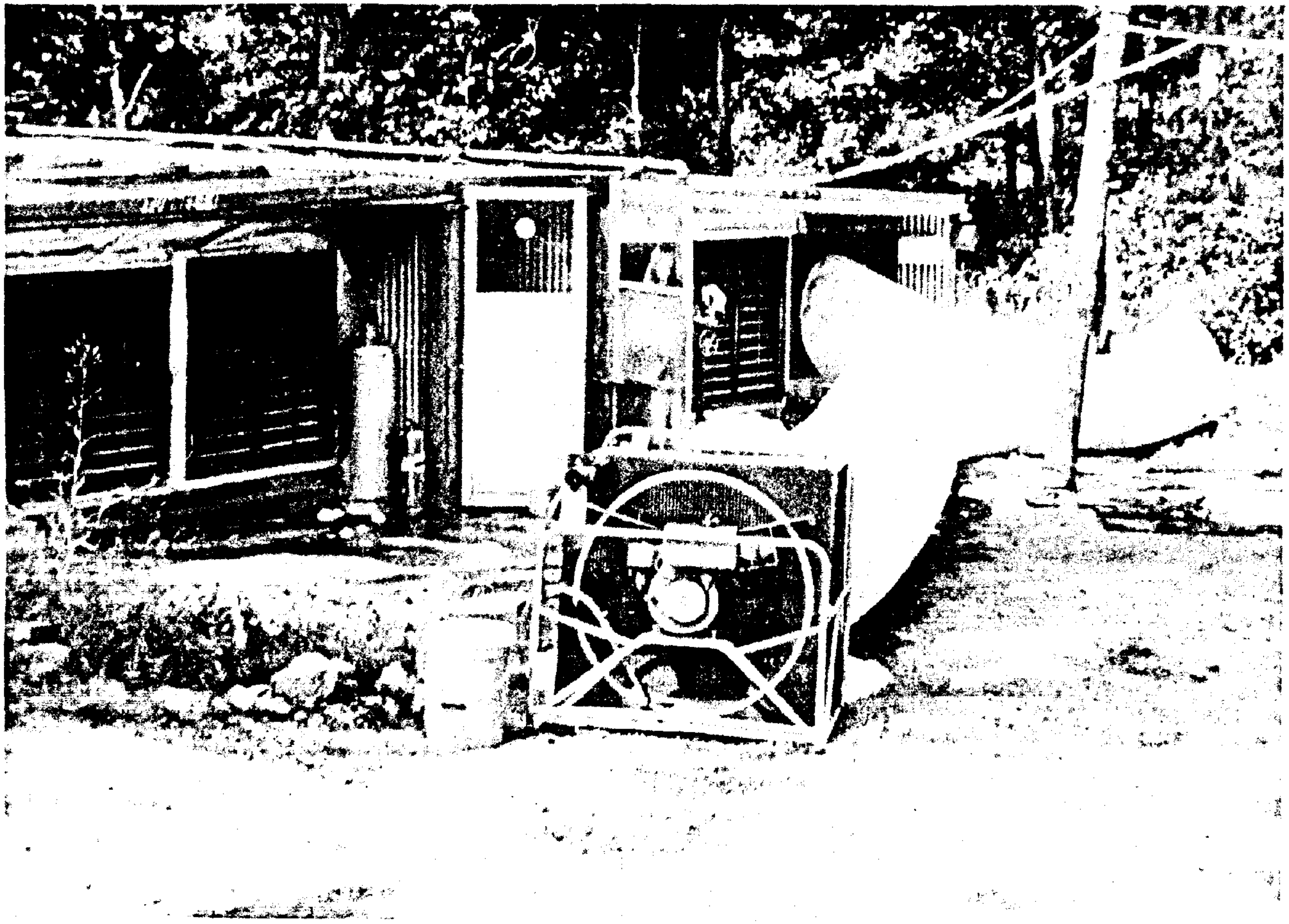


Figure 14

High Expansion Foam Generator and Discharge Chute

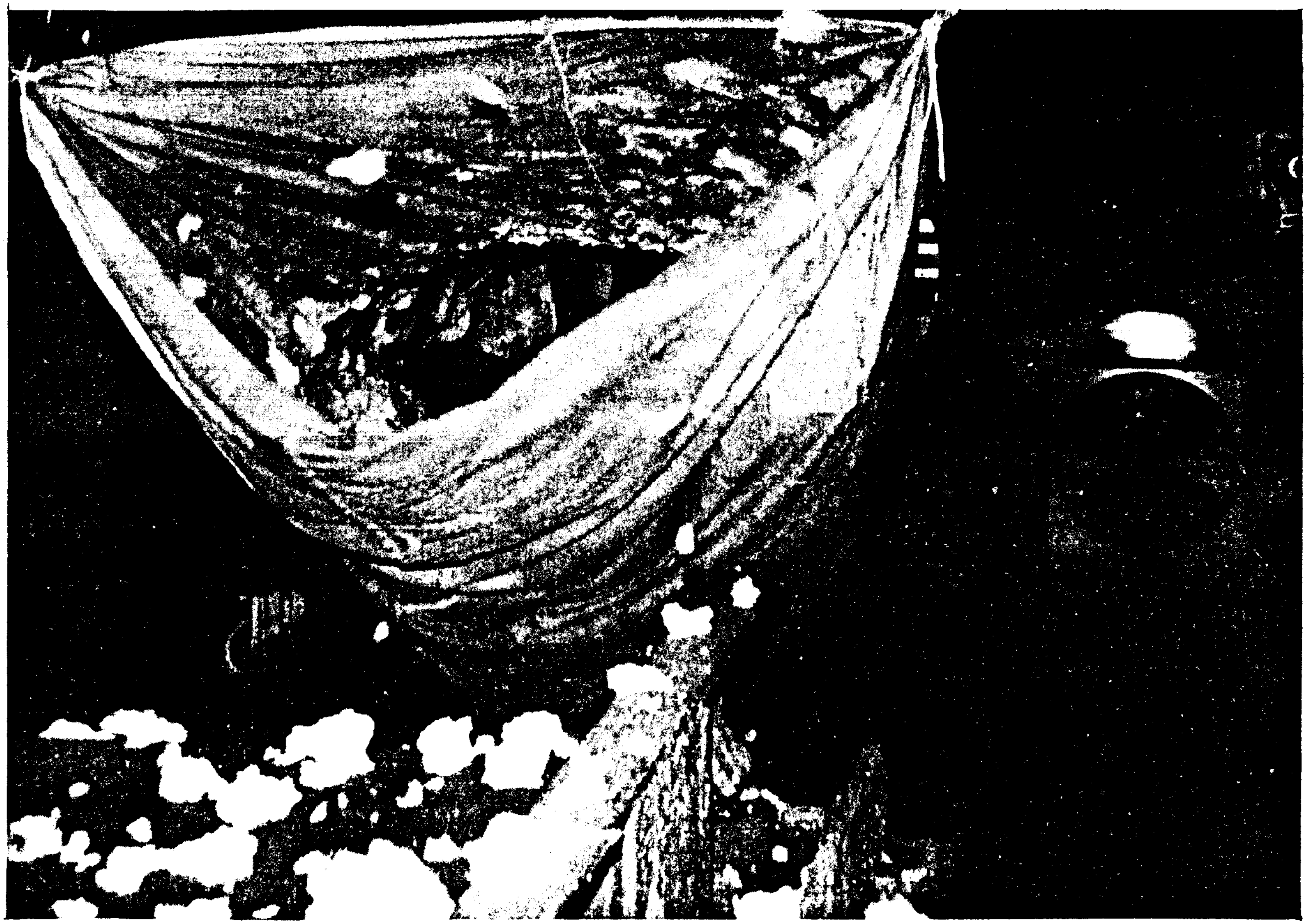


Figure 15

High Expansion Foam Discharge Chute Inside the Test Gallery

High expansion foam was found to be very effective in extinguishing the conveyor belt test fires. The primary criteria for successful extinguishment in this test series was the time within which the foam reached the fire. If this occurred before three or more boards have been charred, successful extinguishment was achieved. On tests where three or more boards did char, the charring occurred before the foam reached the fire. With the "standard" test configuration, i.e., using PVC-3 fire resistant belting, scorching of three or more overhead boards usually occurred within 4 to 5 minutes after ignition. On all tests with high expansion foam, the fire was immediately extinguished when enveloped by the foam.

6.3.1 Standard Test Configuration

With the standard test configuration, a foam discharge rate resulting in extinguishment of the belt fire within 3 minutes was necessary to prevent more than two overhead softwood boards from igniting. Thus, the time from the foam system actuation to extinguishment of the fire was approximately one minute. In test No. 95 in which successful extinguishment was achieved, the foam filled the gallery at a rate of 25 feet per minute, with the discharge chute positioned approximately 15 feet upwind from the point of ignition. The foam progression downwind was greater than upwind, due to the effect of the ventilation air, although the foam did back up against the air flow and through the fans as shown in Figure 16.

6.3.2 Ventilation Air Flow

Tests were conducted with ventilation air velocities of 125 and 350 fpm. At both velocities, especially at 350 fpm, a small gap, usually one foot or less, existed between the top of the foam and the ceiling. In tests where ignition of the overhead boards took place, the glowing embers were not extinguished by the foam. The phenomenon occurred apparently because there was no alternate path for the ventilation air. The foam thus created an orifice, causing the air velocity to increase as the foam depth increased.

At 350 fpm, the ventilation air flow caused the foam to be blown past the belt fire for a short period of time, usually about a minute, before the foam began to accumulate and form a plug. In both tests conducted with 350 fpm air flow (Test Nos. 96 and 97), this delay was enough to result in ignition of three overhead softwood boards, with extinguishment occurring at 5.5 and 4.5 minutes, respectively. As previously mentioned, extinguishment usually must occur within three minutes to achieve successful extinguishment (as defined by the overhead softwood board criteria).

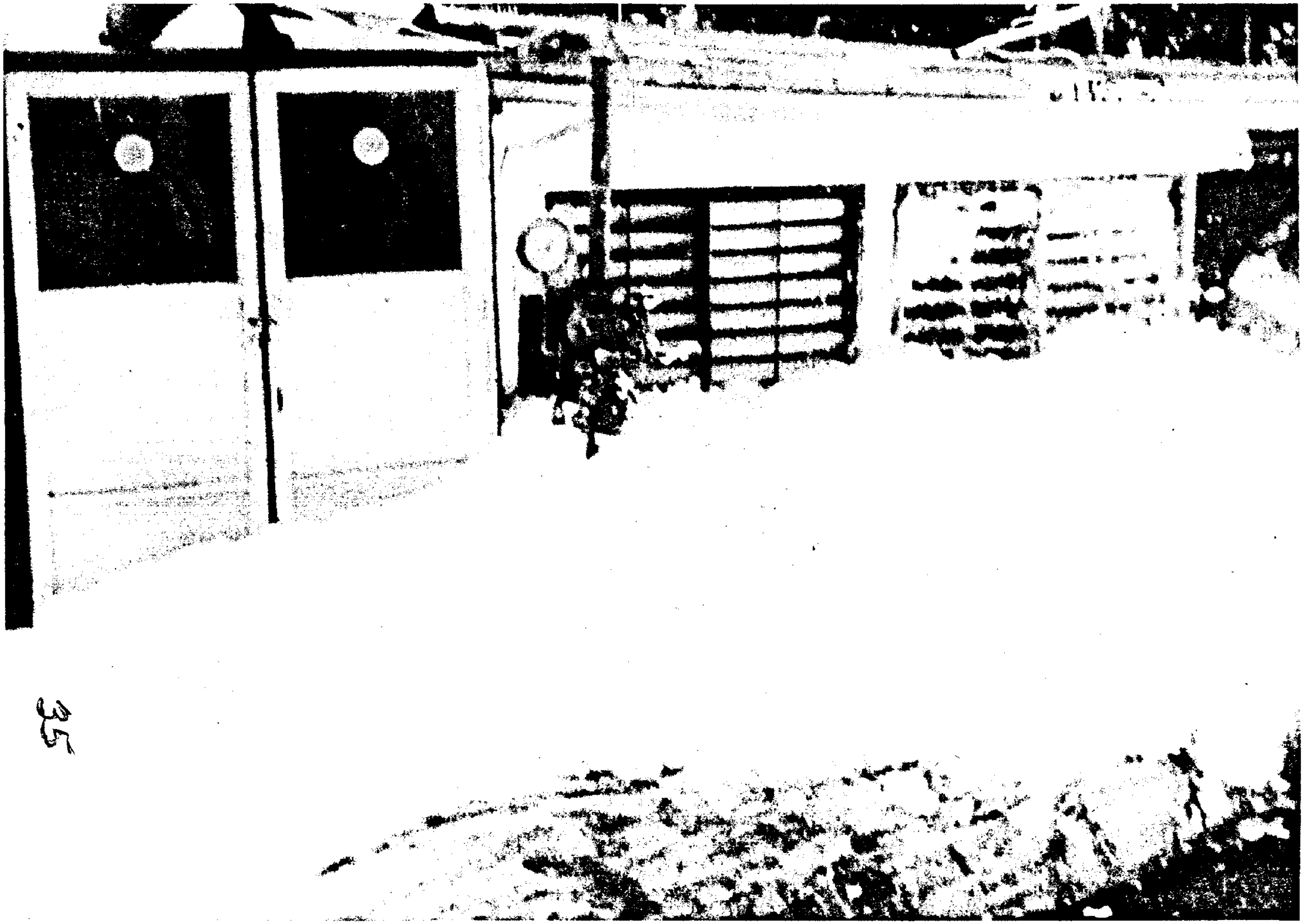


Figure 16

High Expansion Foam Overflowing From Test Gallery

6.3.3 Belt Type

Tests conducted with the FR-2 belting indicated that extinguishment with this belt was also necessary within approximately three minutes to prevent ignition of three or more overhead boards.

6.3.4 Deck Configuration

Since the decking on the conveyor slowed the development of the test fire, actuation of the foam system was delayed until 12.5 minutes to allow for delay in detection of such a fire. Extinguishment occurred in 14 minutes (1.5 minutes after actuation) and no overhead boards ignited in the one test conducted with the decked conveyor.

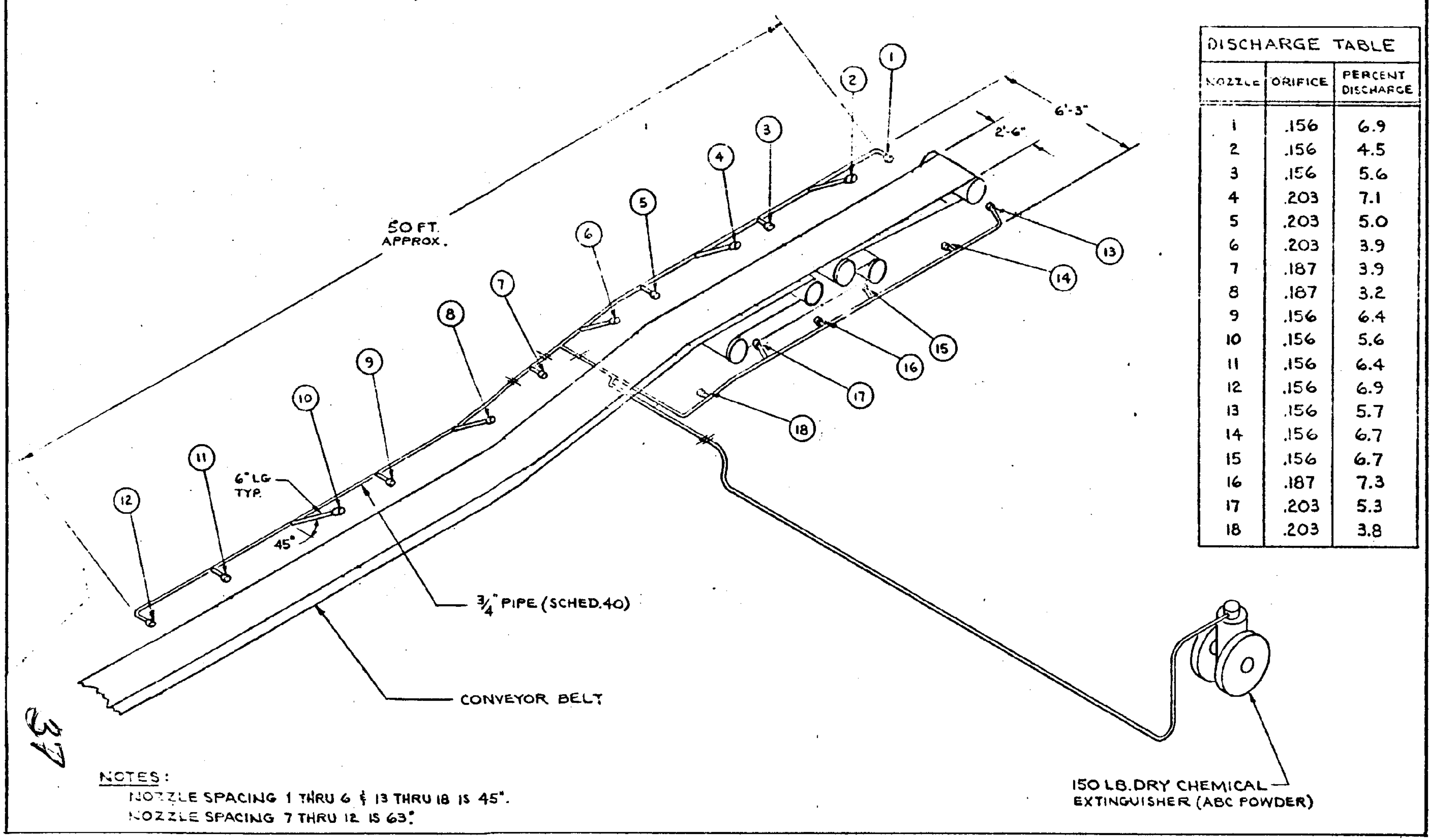
6.3.5 Roof Clearance

No tests were conducted with the conveyor raised to simulate a 1.5 foot roof clearance. The foam normally fills the cross-sectional area of the gallery to within a foot or less of the roof, and would do so regardless of the height of the conveyor.

6.4 MULTI-PURPOSE DRY POWDER

The results of the eleven tests with the ABC multi-purpose powder are listed in Table B-III (Appendix B). The powder system tested was a Kidde system, and provided coverage for 50 feet, including 20.5 feet of the belt run. (See Figure 17.) The system consisted of three branches, one on either side of the take-up and drive mechanism up to the discharge pulley, and one along one side of the 20.5 feet of belt run adjacent to the take-up assembly. Distribution tests were conducted prior to the first fire test with powder to achieve a system design whereby approximately an equal proportion of powder was discharged from each of the three branches. The nozzles were arranged in an alternate pattern such that half were directed horizontally to discharge powder into the lower belt layer(s), and half were directed up at a 45° angle, to direct powder onto the top surface of the top belt. The powder reservoir was a 150 pound extinguisher unit pressurized to 350 psi. The powder used was ABC Multi-Purpose Dry Powder, manufactured by the Ansul Company.

In order to evaluate the worst case conditions, the belt fire was allowed to progress until a belt layer had burned through and separated. This allowed for deep-seated fire in the belt carcass fibres, rather than burning of only coating material. Thus the powder system actuation times varied from one test to another.



DISCHARGE TABLE

NOZZLE	ORIFICE	PERCENT DISCHARGE
1	.156	6.9
2	.156	4.5
3	.156	5.6
4	.203	7.1
5	.203	5.0
6	.203	3.9
7	.187	3.9
8	.187	3.2
9	.156	6.4
10	.156	5.6
11	.156	6.4
12	.156	6.9
13	.156	5.7
14	.156	6.7
15	.156	6.7
16	.187	7.3
17	.203	5.3
18	.203	3.8

NOTES:
NOZZLE SPACING 1 THRU 6 & 13 THRU 18 IS 45".
NOZZLE SPACING 7 THRU 12 IS 63".

Figure 17 - Powder System Diagram, Coal Conveyor Dry Chemical Fire Protection System

As with high expansion foam, the dry powder extinguishing system was fast acting, i.e., the belt fires were immediately extinguished upon release of the powder. If, however, any flames lingered after the powder had been discharged, or if any reignition occurred, repropagation of the belt fire occurred, with the intensity of the flames gradually increasing until the test fires had to be extinguished with hand water hoses.

Since any surviving flames or reignition is likely to result in repropagation of the belt fire, the criteria used to determine successful extinguishment for this test series was whether or not repropagation occurred, rather than ignition of overhead boards.

The only extinguisher system parameter varied was the quantity of powder. Except for tests involving decking on the conveyor structure, all test fires were successfully extinguished with 75 pounds of powder, and some with 50 pounds. This included the standard test fire and tests with 350 fpm air flow and with the FR-2 belting. Figures 18 thru 21 are photos of test No. 114 conducted with 50 pounds of powder and with an air flow of 350 fpm. Figures 22 and 23 show powder penetration and distribution on other tests.

With tests involving decking on the conveyor structure, the powder did not adequately penetrate onto the belt layer under the deck, due to shielding by the side bracing members of the conveyor structure. Also, heating of the conveyor structure may have contributed to the reignition that occurred in these tests, since actuation of the powder system was delayed longer due to slower development of the belt fire. Powder quantities of up to 100 pounds were tested, none of which resulted in successful extinguishment. The design of dry powder systems should therefore insure that the powder will impinge on all belt and other flammable surfaces to insure extinguishment during the powder discharge.

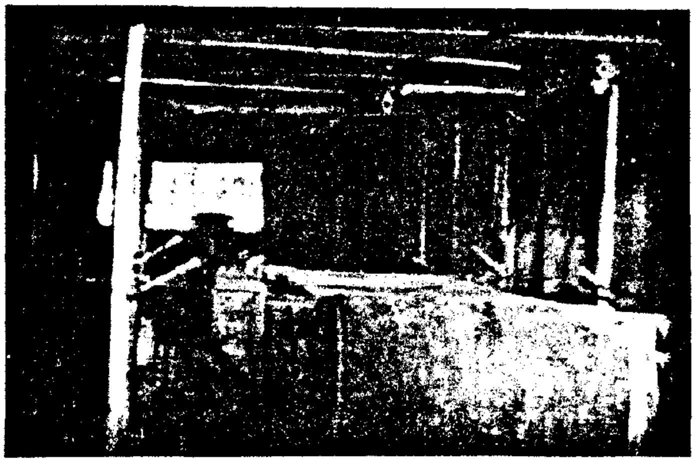


Figure 18

Test Setup for Multi-Purpose Dry Powder (Test No. 114)

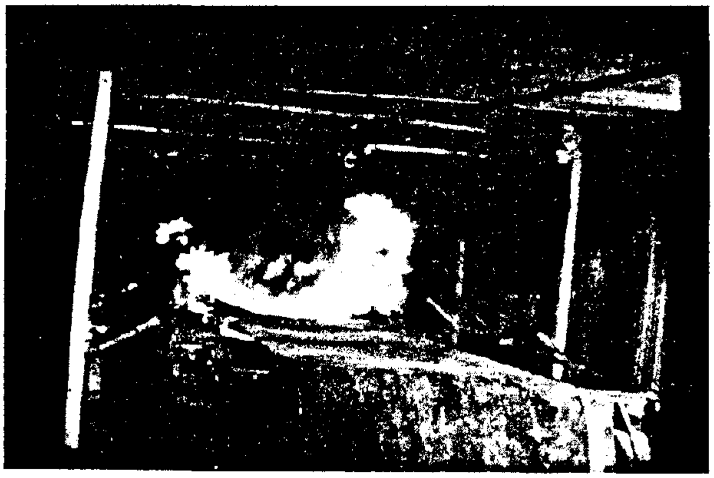


Figure 19

Test Fire Prior to Actuation of Extinguishing System

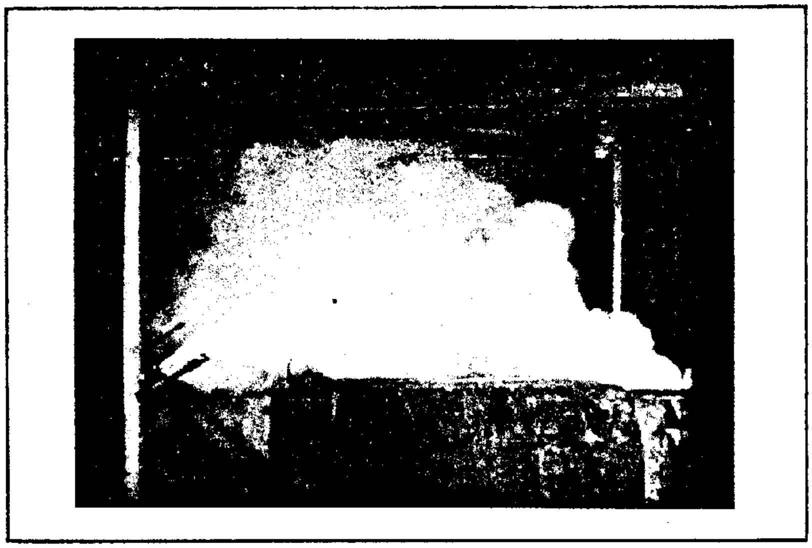


Figure 20

Discharge of Powder

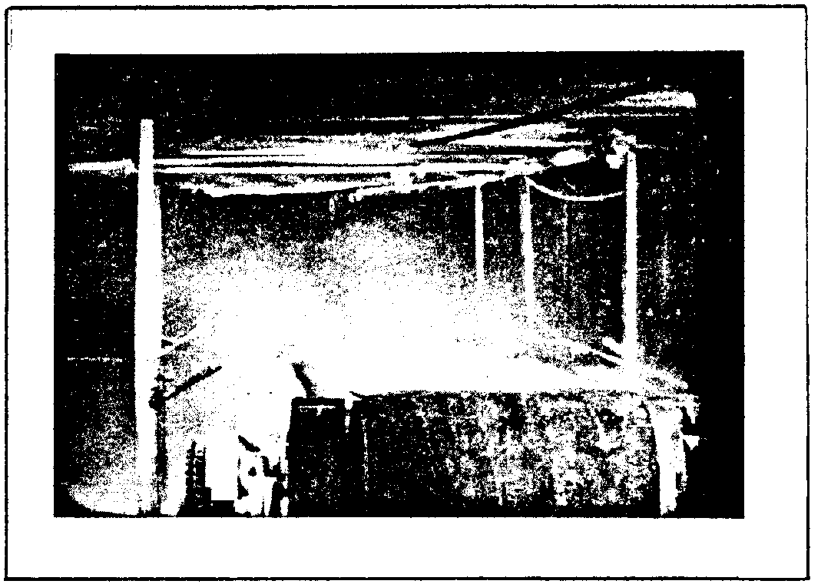


Figure 21

View After Extinguishment

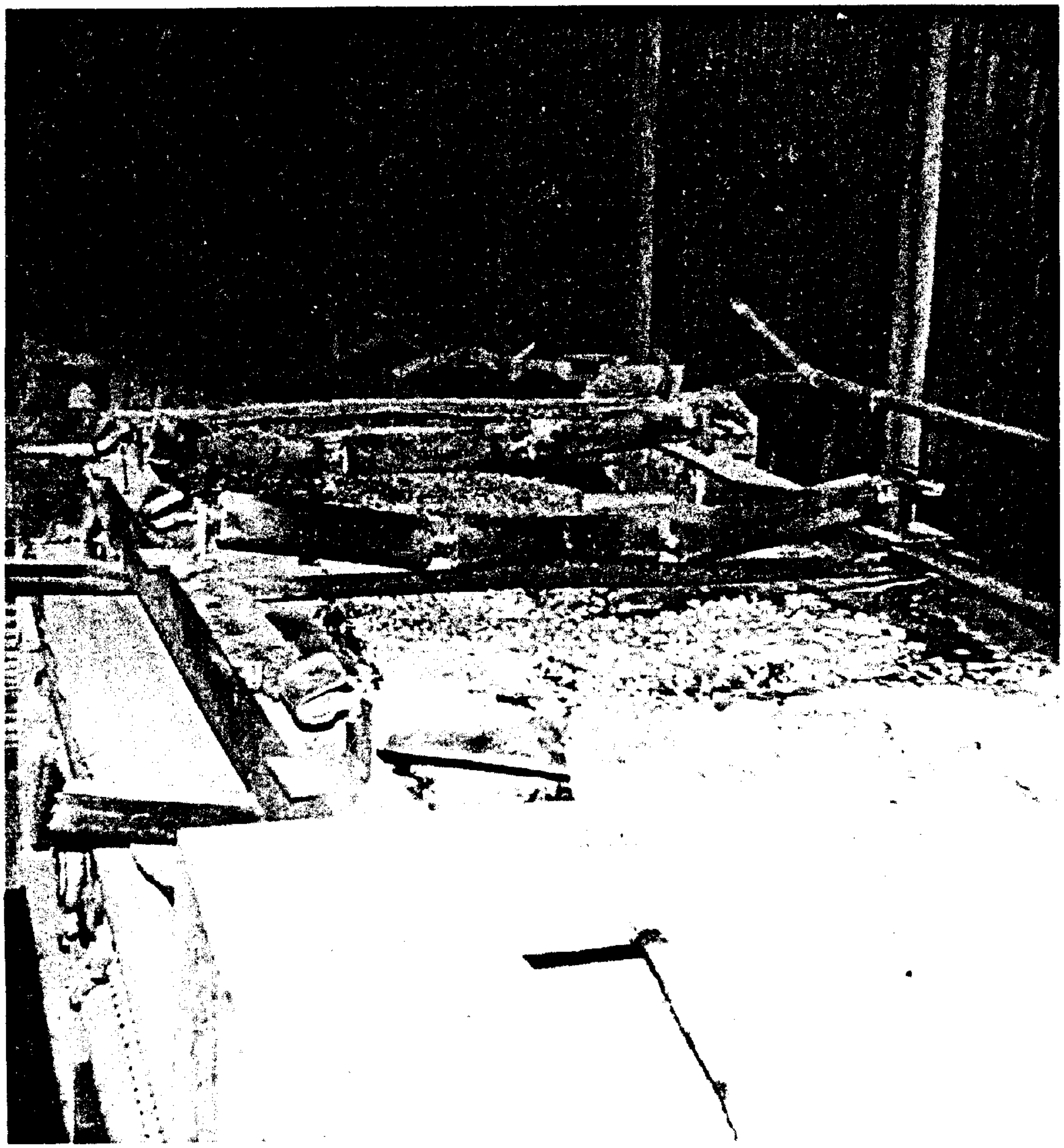


Figure 22

View After Extinguishment Showing Distribution of Powder

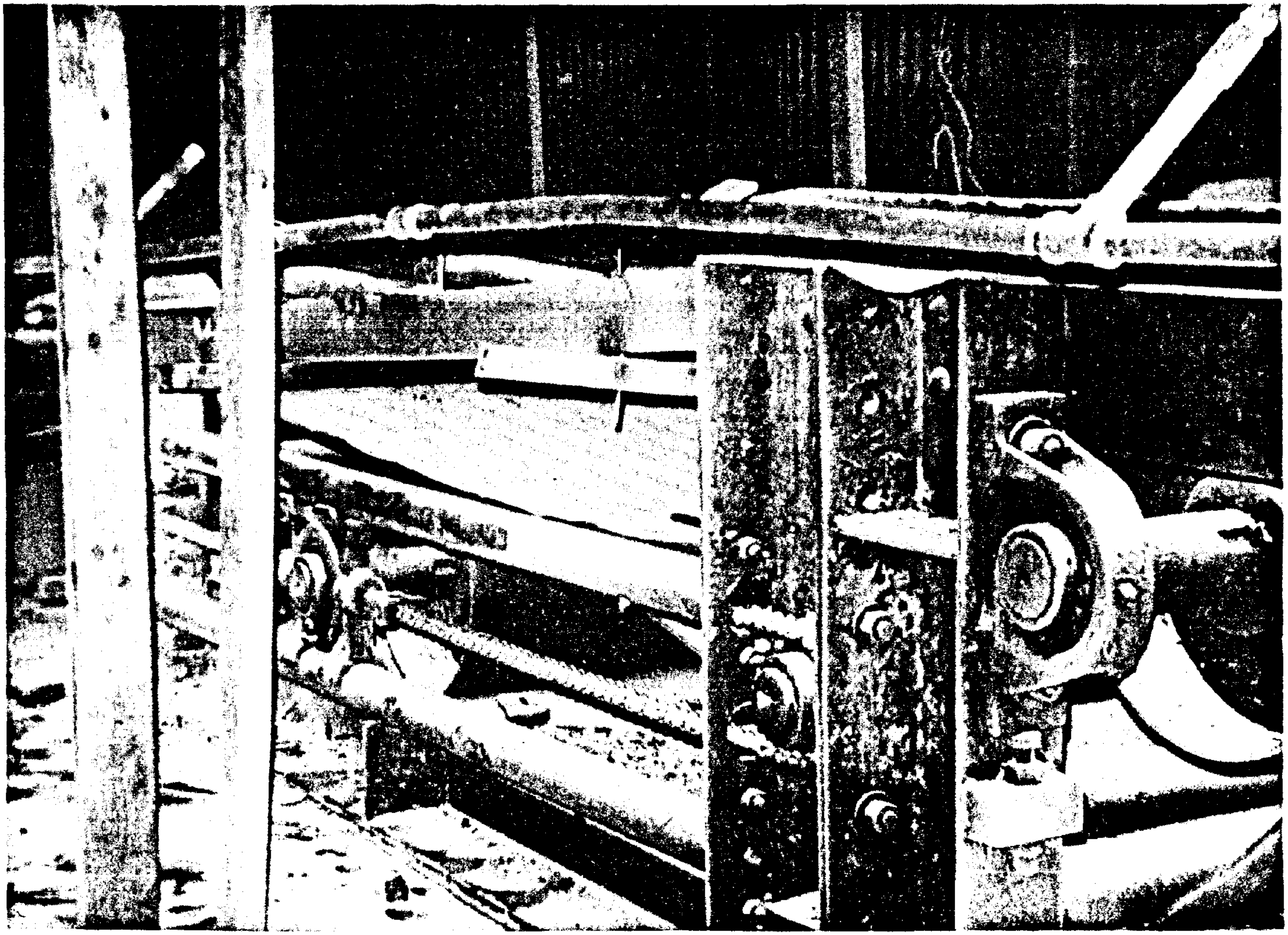


Figure 23

View After Extinguishment Showing Penetration of Powder Into Takeup

7. DETECTION

During the 76 evaluation tests, various fire detection devices were deployed and monitored to determine their effectiveness in detecting coal mine conveyor belt fires. The various types included thermal point, thermal continuous, photoelectric, ionization, ultraviolet, infrared, products of combustion analyzer, and carbon monoxide level measurement. A total of 28 different detector models were tested.

Event recorders were used to monitor detector actuations. Due to the limitation in available recorder channels, approximately half of the detectors were deployed in each gallery, and the locations of the various detectors were changed from one test to another, to evaluate effectiveness at different distances from the belt fires.

7.1 THERMAL POINT DETECTORS

The thermal point type sensors tested included those listed as follows and shown in Figure 24.

TP-1	140° Rate Compensation (Fenwall Detect-A-Fire)
TP-2	135°F Rate Compensation (Thermotech Model 302A-W)
TP-3	136°F Combination Fixed Temperature/Rate of Rise, with explosion-proof base (Fire Devices Spot-Fire-Lowecator)
TP-4	136°F Fixed Temperature, with explosion-proof base (Fire Devices Spot Fire Lowecator)
TP-5	135°F Combination Fixed Temperature/Rate of Rise, with water-tight base (Kidde Fyrindex)
TP-6	135°F Fixed Temperature, with water-tight base (Kidde Fyrindex)
TP-7	135°F Fixed Temperature (Kidde Model S-2)

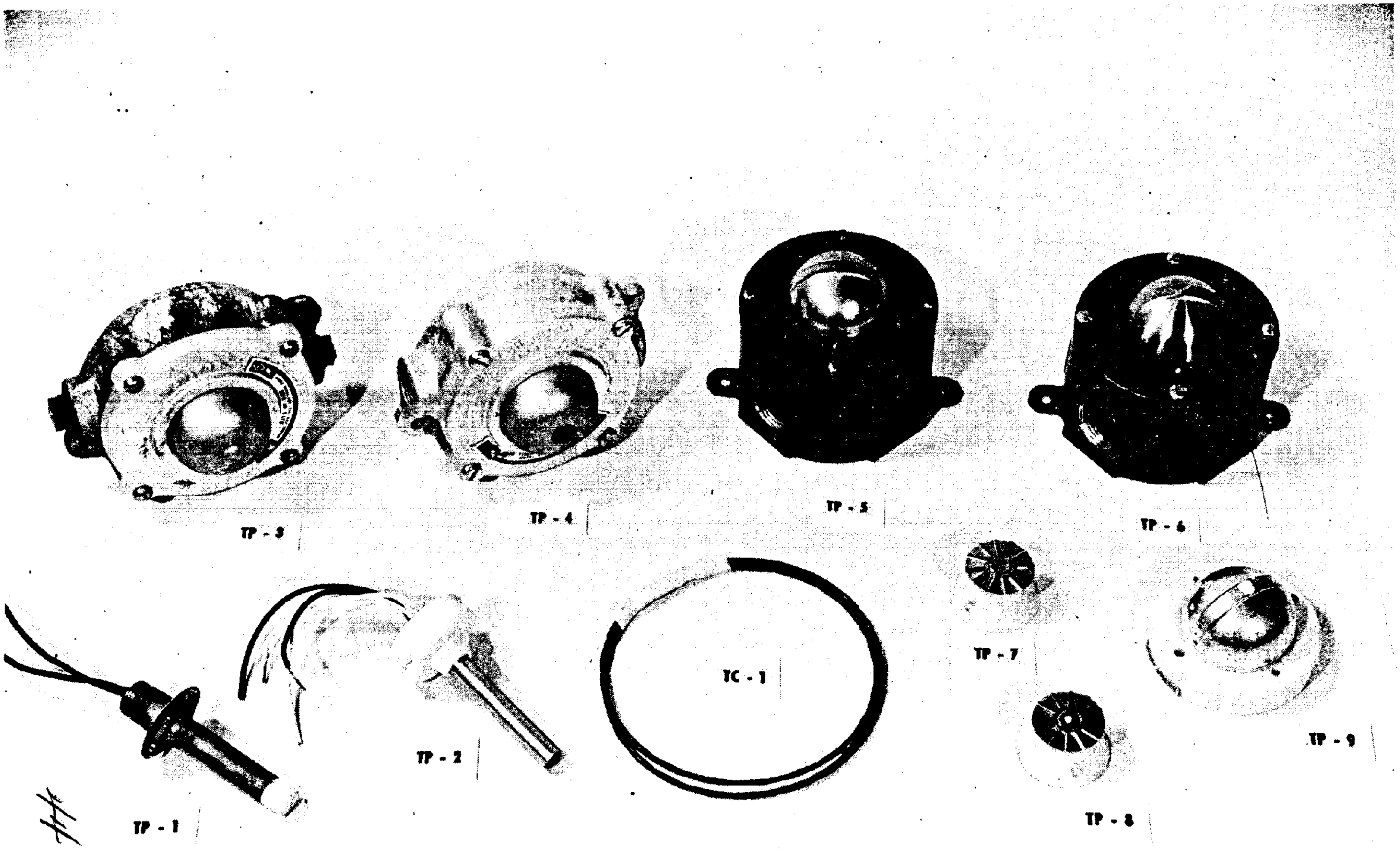


Figure 24

Thermal Point Type Sensors

744152

TP-8	180°F Fixed Temperature (Kidde Model S-4)
TP-9	180°F Fixed Temperature (Kidde Fyrindex)
TC-1	155°F Fixed Temperature (Protectowire)

A rate compensation type detector is one which by definition provides an alarm when the surrounding air temperature reaches the detector alarm temperature, regardless of how fast or slow the temperature rise may be. I.e., the detector is designed to compensate for thermal lag that could result from rapid temperature increases.[5]

The combination rate of rise/fixed temperature types are designed to operate whenever a predetermined rate of temperature increase is sensed, regardless of what the temperature itself may be. The fixed temperature features assures that an alarm will be signalled at the given temperature in the event the rate of increase is slow. The rate of rise feature is based on a pneumatic principle, whereby an increase in pressure within a controlled air chamber due to rapid increase in heat causes actuation. The chamber is vented to prevent normal temperature fluctuations from causing an alarm. The detectors used provide an alarm at a rate of temperature increase of approximately 15°F per minute.

TP-4 and the fixed temperature portion of TP-3 operate on a fusible metal principle, while TP-6 and TP-9, and the fixed temperature portion of TP-5 employ the principle of the bi-metallic strip which changes in curvature as a function of temperature. TP-7 and TP-8 employ a bi-metallic disc whose curvature reverses at the specified temperatures. These detectors are also equipped with heat collectors to improve sensitivity. TC-1 consists of a one-foot strip of a continuous strip detector consisting of twisted steel wires in thermoplastic insulation. Melting of the thermoplastic at the specified temperature results in contact between the steel wires.

The thermal point type detectors were monitored at the five different distances from the drive pulley, as shown in Table IV-a. The drive pulley was used as a reference since it is one of the detection points specified by regulation, and also since it was slightly up-wind (9 feet) from the ignition point. A detector placed here would probably not actuate before the first downwind detector. The distances shown in Table IV-a are therefore representative of detector spacings, rather than distances from the ignition point which would be unknown in an actual fire situation.

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[5] Underwriters' Laboratories, Standard of Safety, Fire Detection Thermostats, UL-521 (June, 1970), p. 6.

TABLE IV-a

THERMAL POINT DETECTOR ACTUATION TIMES (AVERAGE)

	Detector Spacing					
Detector	30 Ft.	40 Ft.	50 Ft.	60 Ft.	100 Ft.	125 Ft.
TP-1	72 sec.	38 sec.	90 sec.	95 sec.	143 sec.	b
TP-2	27	b	b	42	95	b
TP-3	54	a58	a	b	143	b
TP-4	140	a240	a	b	b	b
TP-5	32	38	45	60	103	128 sec.
TP-6	a178	a178	a102	a	185	b
TP-7	54	72	72	91	138	135
TP-8	a	103	b	a118	a	b
TP-9	a	b	b	a	b	a
TC-1	110	a108	b	b	173	a

a - Detector did not actuate in some or all tests

b - Indicates no data was taken at these spacings

TABLE IV-b

SPRINKLER ACTUATION TIMES (AVERAGE)

	Sprinkler Spacing			
Actuation Temp.	8 Ft.	10 Ft.	12 Ft.	15 Ft.
280/286°F	87 sec.	110 sec.	99 sec.	150 sec.
212°F		85	70	115
165°F	30	33	42	

The actuation times shown are averages of several tests at each distance, and include all conveyor configurations tested except those involving conveyor decking. The decking slowed the development of the belt fires significantly, whereas the other variables (roof clearance, air flow and belt type) did not appear to change the fire characteristics significantly. Variations in actuation time in tests involving these variables did not appear to be any greater than the normal variation from one test to another with the "standard" test configuration. As can be seen from Figure 6 on page 21, which shows the temperature profiles of PVC-3 belt fires at neutral, 125 fpm, and 350 fpm air flows, the temperature profiles for the first two minutes are fairly similar. The (a) notations in Table IV-a indicate that the detector did not actuate on some or all of the tests, and the times shown are the averages of the actuations that did occur.

Table IV-b shows the average actuation times for the first sprinkler to actuate in each of the sprinkler tests, and is presented here for comparison with the detector actuation times. Based on the sprinkler actuation times shown, and also on the rate of development of the "standard" test fire, it can be concluded that detector and extinguisher actuation should normally take place within two minutes in order to achieve successful extinguishment of the "standard" test fire.

Based on the two minute criteria, detectors TP-4 and TP-6 did not respond quickly enough on an average, at 30 feet, the lowest spacing tested, to achieve successful extinguishment. TP-9 is also considered unsatisfactory since it did not actuate in any of the tests, and TP-8 and TC-1 are considered marginal. The other detectors appear to respond quickly enough at spacings up to 60 feet, with TP-2 and TP-5 also being suitable at spacings of 100 feet.

The spacings recommended by U.L. and F.M. for the detectors tested are listed in Table V. Also included are the spacings indicated by the two minute alarm criteria as discussed above.

A possible cause for the poor response of sensors TP-4 and TP-6 could be the relatively high mass of their protective bases, which could have acted as a heat sink. TP-3 and TP-5 were also mounted in protective housings, however these were rate-of-rise type detectors which are designed to respond to rapid temperature increases more quickly than fixed temperature devices. TP-9 did not produce an alarm in any of the tests, due to the fact that it had an alarm temperature of 180°F and also that it is mounted in a protective housing. TP-8 was slower than some of the others, probably due to its 180°F alarm temperature, even though its mass was relatively low. TC-1 was also marginal, due very likely to two factors. The two steel wires were insulated with temperature sensitive plastic, and then wrapped with tape to provide added protection. Both the tape and the

TABLE V

THERMAL SPOT DETECTOR SPACINGS

Detectors	Recommended Spacings		Spacings required for detection of test fire within 2 min. (average)
	U. L. a	F.M. b	
TP-1	50 ft.	25 ft.	60 ft.
TP-2	50 ft.	Not listed	100 ft.
TP-3	50 ft.	30 ft.	60 ft. (marginal)
TP-4	15 ft.	15 ft.	Inadequate at 30 '
TP-5	50 ft.	30 ft.	100 ft.
TP-6	15 ft.	15 ft.	Inadequate at 30 '
TP-7	30 ft.	15 ft.[c]	60 ft.
TP-8	N/A [d]	N/A	Data inconclusive
TP-9	N/A	N/A	Inadequate at 30 '
TC-1	15 ft.[e]	15 ft.[e]	40 ft. (marginal)

NOTES:

a. Underwriters' Laboratories, Fire Protection Equipment List, (January, 1974)

b. Factory Mutual System, Approval Guide (1974)

c. Another detector employing the same basic design is recommended for 30 ft. spacings.

d. The U.L. and F.M. spacing recommendations would not apply to TP-8 and TP-9, since these are 180°F detectors, and are recommended for use where the maximum ambient temperatures range from 100°F to 150°F.

e. These spacing recommendations are between continuous element runs.

plastic are relatively poor heat conductors, even though the mass involved is fairly low. Also, this detector operates at 155°F, slightly higher than the faster responding 135°F fixed temperature detector with low mass (TP-7). Of the two rate anticipation detectors (TP-1 and TP-2), TP-1 was lower in mass and faster responding than TP-2.

The response time data shown should not be considered entirely conclusive, however, since most of the tests were conducted with automatic sprinklers. Any detectors that did not actuate prior to the first automatic sprinkler could have been delayed and in some cases prevented from actuating altoghether due to the fire being suppressed by the sprinkler.

It can be concluded, however, that most thermal point type detectors in the 135°F to 165°F range and of relatively low bulk will provide adequate belt head protection at spacings up to 60 feet. That is, this level of detection capability will initiate automatic extinguishing in sufficient time to prevent a belt head fire from getting out of control.

7.2 THERMAL CONTINUOUS DETECTORS

Three continuous type detectors, as listed below and shown in Figure 25 were included in the test program.

TC-2	Thermistor core, averaging, 140°F (when a 20 ft. section is heated) (Kidde)
TC-3	Eutectic salt impregnated core, discrete, 170°F (Kidde)
PN-1	Pressurized thermoplastic hose, 170°F (Air-Lert)

The averaging type thermistor core detector alarms when the average temperature over its 20 foot length reaches 140°F. If a shorter length were heated, the alarm temperature would be higher, such as 210°F if only 5 feet were heated. The detector element consists of two conductor wires embedded in a thermistor core which is contained in an Inconel sheath. The thermistor core decreases in resistance as its temperature increases, and causes the control panel to signal an alarm when the resistance drops to a predetermined level.

The discrete type continuous detector is similar in construction, except that the core is impregnated with a eutectic salt which becomes conductive at its 170°F eutectic temperature. Its alarm temperature remains the same regardless of the length of detector heated.

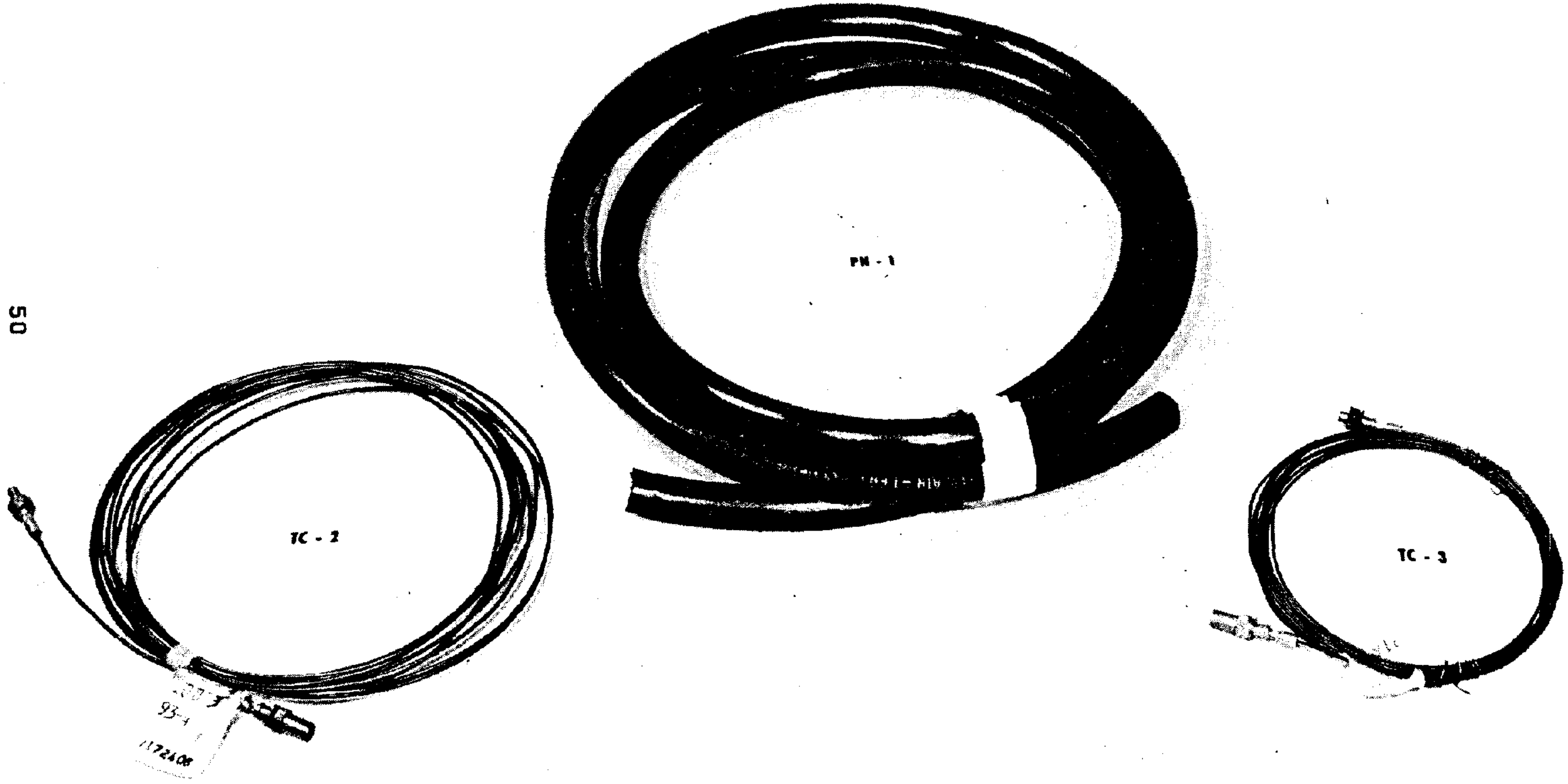

Figure 25

Thermal Continuous Detector Elements

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The pressurized plastic hose is designed to melt at 170°F, resulting in loss of pressure in the hose which causes the control unit to signal an alarm. The system tested is designed for protection of belt runs of 500 to 10,000 feet, although adaptation could easily be made for belt head protection as well.

Twenty foot section of the continuous type detectors were mounted over the belt test sections. Thus, impingement of the fire on the detector was fairly rapid in comparison to the point type sensors. The average actuation times of the thermal continuous detectors were as follows:

TC-2	11 seconds
TC-3	7 seconds
PN-1	120 seconds

Both TC-2 and TC-3 are small in diameter (less than 0.1 inch) and are encased in a metal sheath which is a good conductor of heat. PN-1 on the other hand has an outside diameter of 7/8 inch and is plastic which is not a good heat conductor. These two factors, mass and heat conductivity, are the main contributors to the significant difference in response times. Since the PN-1 detector did average two minutes to respond to the test fires, it would be considered marginally acceptable for belt head protection.

Another factor to consider is the type of control units required. TC-2 and TC-3 are electrical in nature and require electrical circuitry where no moving parts are involved. The PN-1 system on the other hand is pneumatic, requiring a compressor, pressure switches, pressure release valves, and other moving parts. The maintenance requirements for such equipment is typically greater than for electrical systems without moving parts.

7.3 PRODUCTS OF COMBUSTION DETECTORS

Seven different products of combustion detection devices were included in the test program. Three were ionization types, three were photoelectric type, and one operated on a cloud density principle. The detectors tested are listed as follows and are shown in Figure 26:

SI-1	Combination ionization/moisture type (BRK Model SS69C)
SI-2	Ionization type (Pyrotronics Model DI-2)

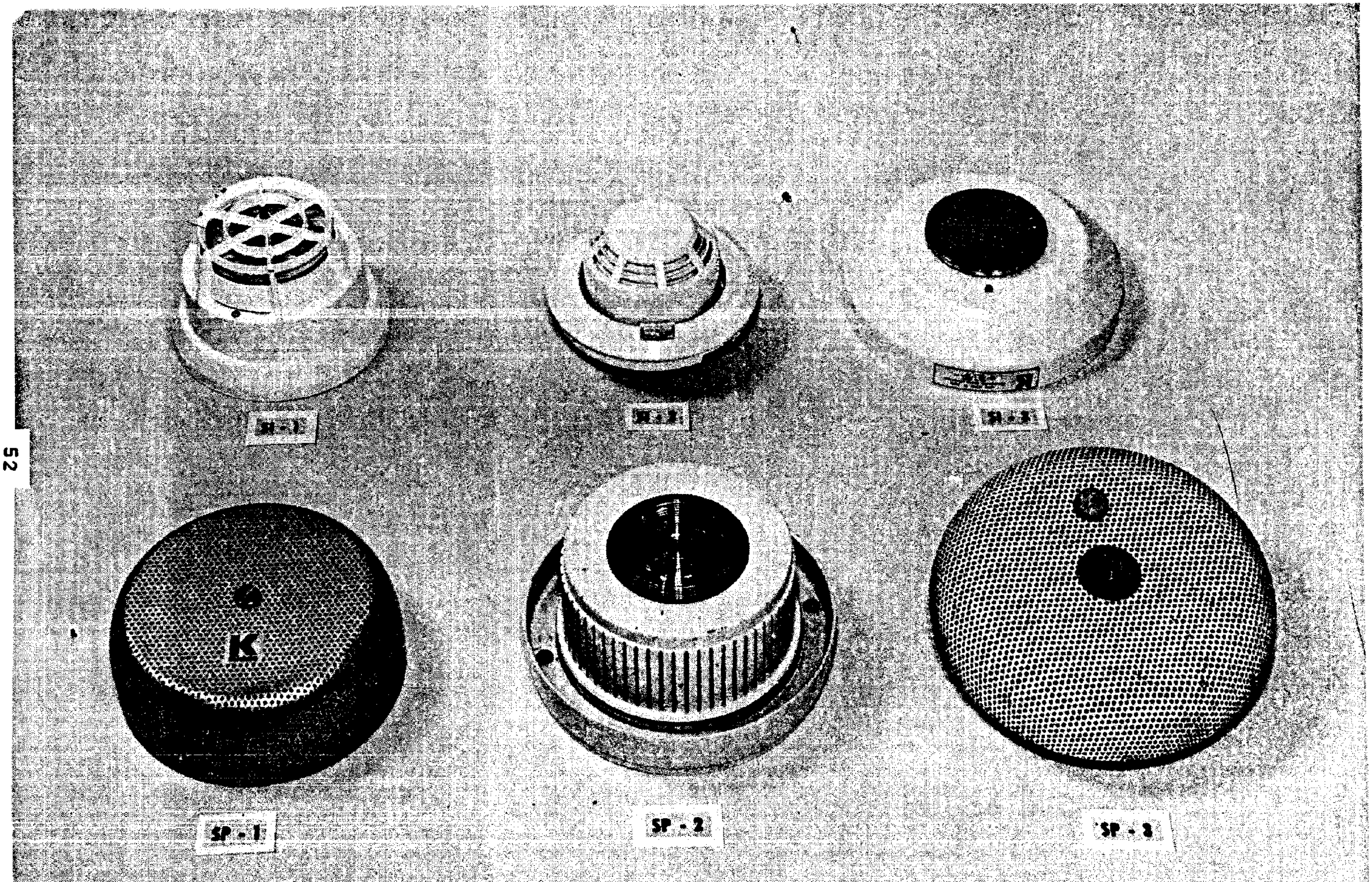

Figure 26

Products of Combustion Detectors

744153

SI-3	Ionization type (Fire Alert Model FT-200)
SP-1	Photoelectric type (Kidde Model PS-1)
SP-2	Photoelectric type (ADEMCO Model 527)
SP-3	Photoelectric type (Pyrotector Model 30-2030-12)
E-1	Products of combustion cloud density type (Environment I)

The ionization type detectors sense products of combustion, both visible and invisible, by passing a continuous air sample through an ionized chamber. Combustion products cause a change in level of a reference current which is passed through the chamber, thus causing an alarm to be signalled. The combination ionization/moisture type detector includes a glass resistance grid type moisture sensor, with operation of both sections required for an alarm to be given.

The photoelectric type detectors sense visible smoke, which causes deflection of a light beam. The deflected light is sensed by a photocell. Other photoelectric type detectors also operate on the principle of obscuration of a light beam, however, the three used in this program are all believed to operate on the light deflection principle.

The E-1 detector, like the ionization types, detects both visible and invisible products of combustion. Operation, however, is by drawing an air sample into a cloud chamber and measuring the cloud density by means of a photo detector. Like the pneumatic type PN-1 continuous detector, the E-1 detector has several moving parts which would be a disadvantage from the standpoint of maintenance needs.

All of the smoke detectors in most tests were mounted near the ends of the test galleries, approximately 125 feet downwind from the point of ignition. In addition, two tests were conducted with the detectors located 100 feet from the ignition point, and one at 300 feet. The 300 foot location was achieved by connecting the ends of the two test galleries and directing the combustion products down one gallery and back up the other.

In some of the tests with the detectors located at distances of 100 and 125 feet, the detectors were actuated by the combustion products generated during the 15 minute preheat prior to ignition. The average times for actuations that took place after ignition are listed in Table VI.

TABLE VI

COMBUSTION PRODUCTS DETECTOR ACTUATION TIMES

	Distance from Ignition Point		
Detector	100 Ft.	125 Ft.	300 Ft.
SI-1	20 sec.	63 sec.	200 sec.
SI-2	25	68	135
SI-3	58	65	
SP-1	55	126	210
SP-2	43	65	180
SP-3	25	50	170

The E-1 detector was included in three tests, and signalled an alarm during the preheat in all three.

As would be expected, actuation times increase as the distance from the point of ignition increases, although there is also some variation in response time due to detector sensitivity. The response times shown in Table VI are averages at 125 fpm air flow. The response times shown at 100 and 300 feet represent only one or two tests, and may not be representative, especially those at 100 feet for SI-1, SI-2 and SP-3. These three appear to be unusually short, due possibly to smoke generated during preheat. The SI-3 detector did not actuate in the 300 foot test due to malfunction.

Malfunction was a problem with the smoke detectors, presumably due to the damaging effects of the relatively corrosive combustion products given off by the burning belt. The number of actuations that took place per detector before malfunctioning ranged from 5 to 15.

7.4 OPTICAL DETECTORS

Seven optical type detectors, as listed below, were tested.

UV-1	Ultraviolet	(Honeywell)
UV-2	Ultraviolet	(Fenwal)
UV-3	Ultraviolet	(Edison)
UV-4	Ultraviolet	(Pyrotector)
IR-1	Infrared	(Pyrotronics Model DF-1)
IR-2	Infrared	(Pyrotector)
IR-3	Near infrared	(Pyrotector)

The detectors were tested at three distances, 50, 40 and 30 feet (approximately), upwind from the point of ignition and at various elevations. The initial tests were conducted at 50 feet and with the detectors located at the roof. Smoke tended to roll forward along the roof, against the ventilation air flow, and it was intially suspected that this was at least partially responsible for the frequent failure of the detectors to actuate. Subsequent tests at elevations 1.5, 2 and 3 feet below the roof produced essentially the same results as at the roof, however, indicating that elevation had little effect on whether or not an alarm was signalled.

As mentioned, the reliability with which the optical type detectors responded to the test fires was poor. When detector actuation did occur, detection was rapid, usually occurring within 30 seconds of ignition, and often occurring simultaneously with ignition. In some instances, however, the ignition torch may have caused some of the detectors to actuate.

Listed below are the percentages of total tests in which actuations took place. Tests involving conveyor decking are not included in these figures, however, since development of the test fire was slowed considerably in those tests. Optical detector actuations were relatively independent, however, of the other test variables, which included air flow, belt type and roof clearance.

As with smoke detectors, the sensitivity of optical detectors can usually be adjusted to the user's needs. This adjustment can even be made in the field on some devices. Higher sensitivity settings do, however, increase the probability of false actuations due to extraneous light sources such as welding operations, electric arcing, vehicle head lamps, cap lamps, and the like. Sensitivity of the above detectors to such extraneous light sources is discussed in the Environmental section of this report.

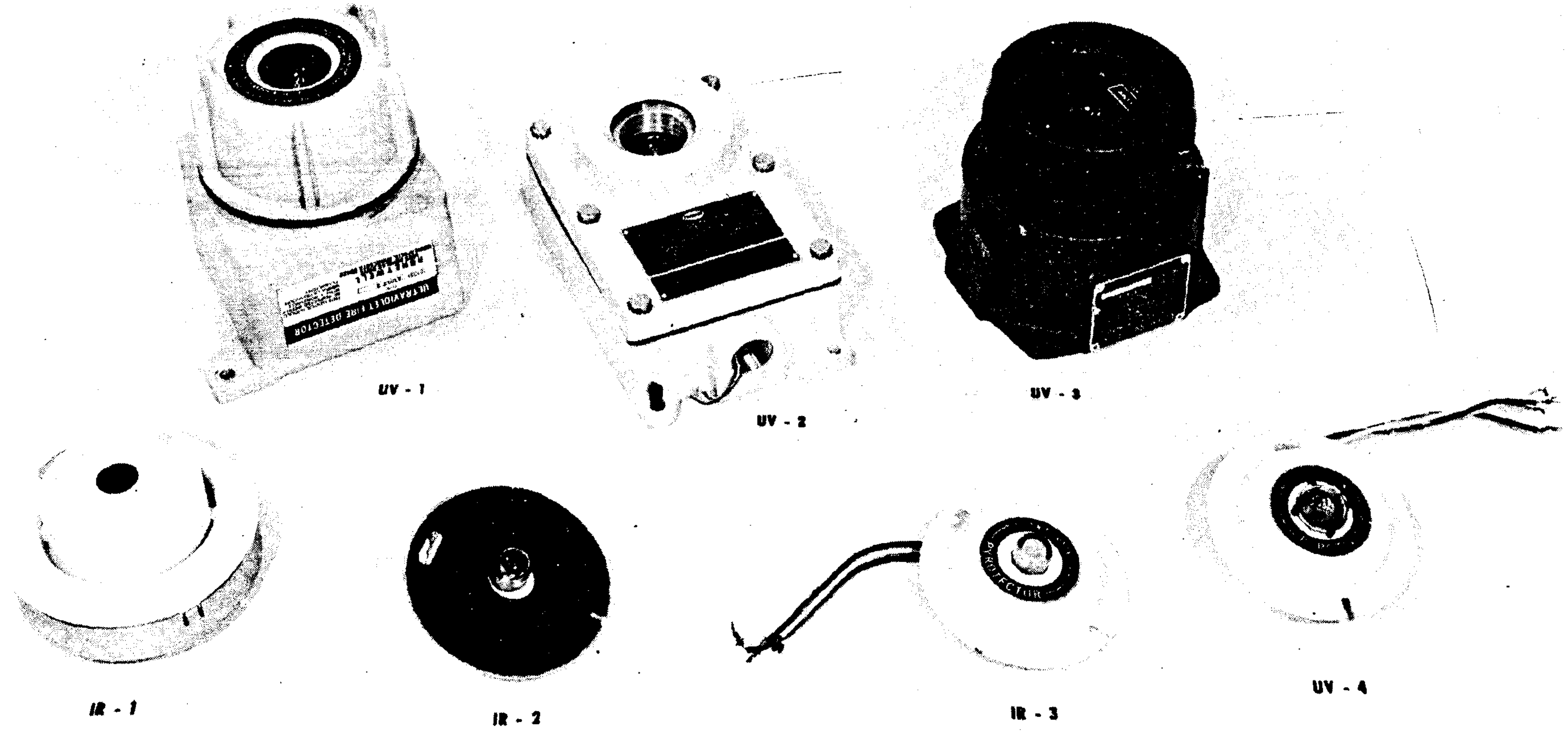

Figure 27

Optical Detectors

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TABLE VII

PERCENTAGE OF TESTS IN WHICH OPTICAL DETECTOR ACTUATIONS OCCURRED

Detector	Distance from Ignition		
	30 Ft.	40 Ft.	50 Ft.
UV-1 (UV)	55%	0%	0%
UV-2 (UV)	13	0	0
UV-3 (UV)	64	0	33
UV-4 (UV)	93	67	40
IR-1 (IR)	90	70	100
IR-2 (IR)	94	28	0
IR-3 (Near IR)	13	0	0

The voltage output of the UV-1 detector was monitored during a test with the PVC belting, and at a distance of approximately 30 feet upwind from the ignition point. The voltage level in that particular test reached as high as 6 volts during ignition when the gas ignition torch was within the view of the detector. After the ignition torch was concealed under the top belt layer, and only the belt fire was in the view of the detector, the voltage level did not exceed 2 volts. The voltage required for alarm was approximately 5 volts.

7.5 CARBON MONOXIDE DETECTION

Measurements of carbon monoxide levels were taken for both the PVC-3 and the FR-2 conveyor belts, at distances of 125 ft. and 60 ft. downwind from the ignition point. The concentration levels ranged from 250 to 500 ppm, with an average of 360 ppm for the PVC-3 belt, and from 150 to 300 ppm with an average of 240 ppm for the FR-2 belt. The concentration levels appeared to be relatively independent of the distance from the ignition point.

The CO level measurements were taken with an MSA squeeze bulb, length of stain type detector. A 10 ft. sampling line with the length of stain cartridge attached to the remote end was used to permit the samples to be taken with the operator standing outside the test gallery.

7.6 CLOSED CIRCUIT TELEVISION

Test No. 111 was conducted with the "standard" test condition, to evaluate the effectiveness of CCTV in detecting smoke concentrations downwind from the fire. The TV camera used in this test was a Motorola Model 1140B, with a Model S1252A 19 inch monitor. The camera was located at a distance of 287 ft. from the test fire ignition point. This distance was achieved by connecting the far ends of the two test galleries, thereby directing the smoke from one gallery around and in the reverse direction through the second. (This is the same test in which data was accumulated on products of combustion detectors located 300 ft. from the ignition point.)

With an air flow of approximately 125 fpm, the first signs of smoke were noticeable on the TV monitor at two minutes, in the form of faint clouds passing by, with a conveyor discharge pulley in the background. As the smoke density increased, the TV picture gradually faded, and was totally obscured within one minute, i.e., 3 minutes from ignition. Billowing smoke could be seen on the monitor before the picture became too badly faded due to the overall smoke density, i.e., it was fairly obvious that smoke was present.

8. ENVIRONMENT

Environmental testing was conducted to evaluate the ability of the various detection devices to withstand the effects of the various environmental conditions to which they might be exposed in an underground coal mine. Testing consisted of subjecting the devices to the various environmental conditions and observing for inoperable conditions, false actuations or changes in sensitivity.

In the case of some environmental conditions, their effects on detection devices can be determined by design analysis, or by reviewing existing test data. Such analyses and reviews are included where applicable.

The various environmental conditions considered and the methods of evaluation are as follows:

Environment	Detection Devices	Method of Evaluation
Suspended Coal and Rock Dust	Products of Combustion	Test
Dust Accumulation	Optical and CCTV	Test
Alien Light	Optical	Test
Hot Lubricant Fumes	Products of Combustion (Ionization Type Only)	Test
Water Spray	Products of Combustion	Test
Pressure Variation	Thermal Rate of Rise	Design Analysis
Vibration	Thermal Continuous	Data Review and Analysis
Impact	All Types	Analysis

In addition to the above tests, samples of the detection devices were placed near an operating belt head in the Bethlehem Cambria No. 33 coal mine in Cambria County, Pa., for approximately five months. Due to the limited exposure period, however, and also since the detector samples were not powered, the data obtained is limited to effects of dust accumulation. Discussions of the test results are included in the following section on dust accumulation.

8.1 SUSPENDED COAL AND ROCK DUST

The ionization type products of combustion and the photoelectric type smoke detectors were subjected to a test in which they were placed in a dust laden air stream to determine if and at what level such an environment would cause false actuation or render the detectors inoperable. The dust laden air stream was produced by introducing and recirculating dust through a tank type shop vacuum. The tank was equipped with a bracket to which the detector test samples were mounted during the test. The dust used was a mixture of 50% rock dust and 50% coal dust. The rock dust was the type commonly used in coal mines, and the coal dust had a maximum particle size of 74 microns.

The test units, with power applied and the alarm output monitored, were subjected first to a minimum amount of dust by exhausting the dust from the previous test and operating the test device with only the small amount of residual dust still in the system. If this did not cause the test sample to malfunction, the test was then repeated with 2 oz. of dust introduced into the system. If still no malfunction occurred, the test was again repeated with 4 oz. of dust. Each detector sample was checked for response to smoke before and after each dust test. The duration of exposure to dust in each test was two minutes, or until malfunction occurred. The test results are listed in Table VIII.

TABLE VIII

DUST EXPOSURE OF COMBUSTION PRODUCTS DETECTORS

	Dust Exposure		
Detector	Residual	2 oz.	4 oz.
SP-1	OK	Alarm	-----
SP-2	Alarm	------	-----
SP-3	OK	OK	Alarm
SI-1	OK	Alarm	------
SI-2	OK	Alarm	-----
SI-3	OK	Alarm	-----

In all of the above tests, the detector test sample reset after being removed from the dust laden air stream, and responded to smoke when functionally tested. This would indicate, then, that both ionization and photoelectric type smoke detectors could be actuated by dust in heavy concentrations, such as during rock dusting operations. The volume of the test chamber and connecting hoses was approximately two cu. ft. The dust concentration with two oz. of dust would therefore be approximately one oz. per cu. ft., and four oz. would correspond to two oz. per cu. ft.

8.2 DUST ACCUMULATION

Tests were performed on the UV and IR detectors, and with the CCTV camera to evaluate the effects of accumulations of coal and/or rock dust on the effectiveness of these devices. The dust used in these tests, as in the suspended dust tests, was a mixture of 50% rock dust and 50% coal dust, the coal dust having a maximum particle size of 74 microns. Dust accumulations were deposited on the lenses of the tested devices by mixing the dust with water and spraying repeatedly to achieve progressively heavier layers of dust. To achieve even heavier accumulations, the lense was moistened and dust sprinkled on. The excess dust was then gently blown away.

The degree of obscuration was measured by depositing a like amount of dust on a glass plate and measuring the intensity of light passing through from a fixed light source. This was done by placing a cap lamp in one end of a box and directing it toward a photographer's light meter inserted into the other end of the box. The glass plate was then placed in the box to intercept the light beam, and the light meter readings recorded in foot candles.

8.2.1 Optical Detectors

The effect of the dust on the UV and IR detectors was measured by measuring the distance at which the detectors would actuate when exposed to flames from burning conveyor belting. The belting was burned in a refuse can in the test gallery and produced a flame approximately two feet wide by three feet high. Eight tests were conducted on each detector, once without dust, once after each of six sprayings with the water/dust mixture, and once after sprinkling dust onto the moisten lens. In each test, the detector was moved toward the flame, starting from 40 feet, until the detector actuated.

As can be seen from Table IX, the adverse effect of dust accumulations is greater for UV detectors than for IR types.

TABLE IX

DUST ACCUMULATION ON OPTICAL DETECTORS

Spray Applications	0	1	2	3	4	5	6	Caked
Light Intensity (f/c)	56K	48K	38K	38K	32K	22.5K	19.5K	2K
% Obscuration	0	17	32	32	43	60	65	96
Detector	Actuation Distance (ft)							
UV-1	40	36	17.5	29	22	13	14	9
UV-2	40	17	10	8	10	3	8	0
UV-3	40	35	36	40	32	11	25	11
UV-4	40	40	40	40	40	40	40	9
IR-1	40	37.5	35	40	39	36	32	37
IR-2	40	40	40	40	40	40	40	40
IR-3	18	8	6	15.5	11	10	3	3

Two areas of difficulty encountered in conducting the above tests were in achieving uniform concentrations of dust on the detector lenses and the glass plate, and in producing a belt fire of the same intensity for each test.

Two of the UV detectors with removable lenses, which were placed in the coal mine, were also checked for degree of obscuration due to dust accumulation. The detectors were checked while still at the mine, after being brought to the surface, so that the dust accumulations would be disturbed as little as possible. One of the detectors had been in the mine for 2-1/2 months, and the other 5 months. The reduction in light beam intensity of each was 50% and 75%, respectively. The dust accumulations on the mine samples, based on color, appeared to be mostly coal dust, containing very little rock dust.

Based on the results of the dust accumulation tests conducted in the test galleries, the dust accumulations on the mine samples would significantly reduce the range of UV type detectors, and would dictate the need for frequent cleaning of the lenses if they were to be used. The dust problems with IR detectors does not appear to be as severe, however, periodic cleaning of this type would also be necessary. The frequency of cleaning necessary for either type would depend, of course, on the amount of airborne dust present in the given mine situation.

8.2.2 CCTV

The dust test on the CCTV camera was conducted by sprinkling dust on a moistened glass plate, and holding the glass plate in front of the TV camera. The TV monitor was then observed to determine at which concentration of dust it was felt that the TV picture became sufficiently obscured to no longer be effective for viewing the presence of smoke in the belt haulageway. This dust concentration was then checked for percent obscuration with the light beam and photocell method used for the optical detectors. In the judgement of the two persons viewing the TV monitor, this point occurred at approximately 80% obscuration. At this point, the TV image was still clear enough to be able to see billowing smoke, although the person assigned to monitor the CCTV system would have to be fairly alert to notice such an event. Even if the billowing smoke was not observed, the increasing smoke level would soon result in total obscuration of the TV image, thereby alerting the observer to a problem situation. In the belt fire test with a clean TV camera lens, the time interval from the initial observation of smoke until total obscuration occurred was approximately one minute.

8.2.3 Products of Combustion Detectors

The six products of combustion detectors (three ionization types and three photoelectric visible smoke types) placed in the coal mine were also checked for operation after being brought to the surface. All had been in the mine for the entire 5 months duration. One photoelectric and one ionization type detector went into alarm when power was applied, and one ionization detector operated intermittently when subjected to tobacco smoke. These three samples then functioned properly after being cleaned. When subjected to a belt fire test, all samples except the third ionization type provided an alarm. This and the two photoelectric types which responded to tobacco smoke after removal from the mine, were not cleaned before being subjected to the belt fire. The ionization detector was again checked with tobacco smoke after the belt fire test, and did go into alarm, indicating that the dust accumulation from the 5 month mine exposure caused the sensitivity level to decrease too low to sense the belt fire. This and the two photoelectric units were then also cleaned and subjected to two additional belt fire tests, with all samples responding to both tests.

The test results on the mine samples indicate, therefore, that false actuations, inoperative conditions and/or decreased sensitivity could result with products of combustion type detectors from long term exposure to the mine environment. Since the units operated satisfactorily after being cleaned, it can be concluded that the malfunctions resulted from dust accumulations in the circuitry and, in the case of the ionization type detectors, in the ionization chamber.

8.3 ALIEN LIGHT

The UV and IR detectors were subjected to three sources of alien light, a miner's cap lamp, a 12 volt automotive head lamp, and a 25 volt welding arc with a current of up to 225 amps. These sources are intended to simulate alien light sources that could exist in a mine, such as vehicle head lamps, arcing trolley wires, welding operations, etc. The light sources were held in a fixed location, while the detectors were moved toward the source, starting with a distance of 40 feet.

The test results are shown in Table X.

TABLE X

EXPOSURE OF OPTICAL DETECTORS TO ALIEN LIGHT

Detector	Distance of Actuation		
	Head Lamp	Cap Lamp	Welding Arc
UV-1	-----	-----	40' (max. distance tested)
UV-2	-----	-----	40'
UV-3	-----	-----	40'
UV-4	-----	-----	-----
IR-1	8'	10'	7'
IR-2	40'	40'	11'
IR-3	-----	-----	40'

The IR-1 infra-red detector is designed with a 5 second delay to prevent light source of short duration from causing an alarm. The actuation times for IR-1 at the distances shown in Table X ranged from 6 to 9 seconds. IR-3 responded to the welding arc in 4 seconds, and all other detector actuations took place in less than one second.

As can be seen from the data, the two IR detectors responded to all three light sources. Sensitivity to a cap lamp, especially, is a serious disadvantage, since exposure to this light source would normally be frequent. The Near IR (IR-3) and three of the UV detectors responded to only the welding arc. Use of these detectors would require protection against exposure to any electric arcs.

8.4 HOT LUBRICANT FUMES

The ionization type product of combustion detectors were subjected to fumes from #2 multi-purpose grease (Texaco Marfak), heated to various temperatures. The grease was placed in a 10" diameter cast iron pan and heated over a gas burner. The temperature of the grease was monitored by a thermocouple placed in the pan. Tests were conducted at grease temperatures of 175°, 200°, 250°, 300° and 350° the grease was heated to slightly above the test temperature, and the pan was then held under the detector unit for a period of 3 to 4 minutes, until the grease temperature has decreased to below the test temperature.

The test results are as follows:

Detector	Grease Temp. for Actuation
SI-1	None (Up to 350°F)
SI-2	200°F
SI-3	250°F

As the grease was heated, a slight amount of visible smoke was emitted at approximately 200°F, with increasing amounts being emitted as the temperature increased. Since the ionization type detector is designed to respond to particles of combustion, both visible and invisible, it would be difficult to determine if the visible or invisible grease fumes, or a combination of both, caused the two detectors (SI-2 and SI-3) to actuate.

8.5 WATER SPRAY

The products of combustion detectors, both ionization and photoelectric (visible smoke) types, were subjected to water spray to simulate the effects of dust suppression water sprays in the mine. The detectors were mounted on the ceiling of the test gallery, and power was applied. The detectors were then sprayed with tap water, for approximately five minutes. The outputs of the detectors were monitored by event recorders, the same as in the fire tests. Following the water spray test, the detectors were subjected to a belt fire test, to determine if those detectors not actuated by the water spray would still react to smoke from a belt fire.

The test results are shown in Table XI.

TABLE XI

EXPOSURE OF COMBUSTION PRODUCTS DETECTORS TO WATER SPRAY

Detector	Actuated by Water Spray	Actuated by Subsequent Belt Fire
SI-1	Yes	-----
SI-2	No	Yes
SI-3	No	Yes
SP-1	Yes	-----
SP-2	No	Yes
SP-3	Yes	-----

As can be seen from the test data, one of the three ionization type detectors was actuated by the water spray, as were two of the three photoelectric types. Since smoke detectors must be of open type construction to permit the entry of smoke into the device, it is likely that all such detectors would eventually be adversely affected by exposure to water spray over a period of time. Thus, such exposure should be avoided.

Exposure of thermal type detectors to water spray should also be avoided. Impingement of water on this type detector would tend to cool the detector, and delay or even prevent its actuation in the event of a nearby fire.

8.6 PRESSURE VARIATION

The thermal rate-of-rise type detectors included in this program (TP-3 and TP-5) operate on a pneumatic principle whereby rising temperatures cause the pressure in an air chamber in the detector to increase and operate a diaphragm type pressure switch. The chamber is vented to prevent normal temperature and pressure variations from causing alarms, however pressure changes greater than the rate at which the detector is set to operate will cause an alarm. Such pressure changes could result from turn-on or turn-off of ventilation systems.

The Underwriters' Laboratory standard for rate-of-rise detector sensitivity is not less than 12°F temperature rise per minute, with most detectors set to operate at 15°F or more per minute. The manufacturer of one of the rate-of-rise detectors tested estimates that with a sensitivity of $15^{\circ}F$ per minute, actuation of his detector could result from a decrease in ambient pressure as little as 3 to 4 inches of water per minute. Pressure drops in a mine could very well exceed this rate, being as high as 12 to 13 inches of water per minute, based on information supplied by a ventilation fan manufacturer, and possibly higher, expecially in areas near the ventilation fans where the pressure change is greater and more rapid than in areas further away.

In situations where the detectors are mounted on explosion proof or water tight bases, the pressure change in the detector air chamber is relative to the pressure in the base housing. Thus, if the base housings are sealed from the surrounding atmosphere, the detectors would then be virtually insensitive to changes in ambient pressure.

8.7 VIBRATION

Thermal continuous detectors are sometimes mounted on conveyor structure in belt head fire protection systems. In such installations, therefore, the detectors must be able to withstand vibration resulting from operation of the conveyor. Continuous type detectors TC-2 and TC-3 are the same types used in aircraft fire detection and are designed to meet the high vibration requirements necessary for aircraft engine installations. These requirements include being able to withstand vibration from 5 to 500 Hz at a maximum double amplitude of 0.10 inch and a maximum acceleration of 20 g.[6]

Since vibration can have only an adverse effect on fire protection, or any type equipment, installations on conveyor or other vibrating structure should be avoided whenever possible.

8.8 IMPACT

Any fire protection system should be designed and installed to prevent its being struck by material being conveyed. It must be assumed that any device in the path of material that could spill from the belt will eventually be damaged, and that the damage would not likely be discovered until failure occurs, whether after the first impact or after many impacts. Even if tested, a device that were to survive several test impacts could still not be considered reliable, since the potential would always exist for it to be struck at just the right angle to cause damage, or simply to be struck just too many times. The best policy is to avoid such installations, and where they cannot be avoided, frequent inspections should be the rule.

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[6] Federal Aviation Administration, Technical Standard Order Clld, (Washington D.C.: August, 1961), p. 2.

9. CONCLUSIONS AND RECOMMENDATIONS

A significant factor with regard to the validity of this test program is the fact that the testing was full scale. Thus, the heat generated by the belt fires was representative of the heat generated in an actual mine fire, and consequently the effectiveness of the various fire protection systems is representative of their effectiveness in suppressing a belt fire in an actual mine situation. This program did, however, involve the conveyor belt as the only combustible (other than the coal seam and/or overhead support timbers, which were simulated for purposes of ignition), whereas some actual mine situations could involve other combustibles as well.

Also of importance is the criteria by which the test results are evaluated. In the case of automatic sprinklers and high expansion foam extinguishing systems, this criteria was the ignition of overhead softwood boards which were intended to simulate overhead coal and/or support timbers with regard to ignition. This criteria was recommended by the Bureau Technical Project Officer as being valid, and is probably more severe than the actual hazard, thereby introducing a safety factor into the protection systems judged adequate based on this criteria.

9.1 RECOMMENDATIONS FOR CONVEYOR BELT FLAMMABILITY TESTING

The preliminary test phase of this program has revealed that in a full-scale fire situation, the PVC-3 new PVC conveyor belting burns with greater intensity and propagates faster than the new nonfire-resistant rubber belting tested. In a small scale test closely approximating that of Bureau of Mines Schedule 2G, paragraph 18.65, Flame Test of Conveyor Belting and Hose, the PVC rubber belt sample did self-extinguish within the specified time limit, whereas the nonfire-resistant rubber belt sample did not. When the 300 fpm air flow specified in the Schedule 2G test was not applied in a test on the PVC sample; however, the flame did not self-extinguish within the specified time, but in fact burned at a steady rate until the entire sample was consumed. Application of the 300 fpm air flow tended to blow the flame out on the PVC sample.

These observations tend to reveal a basic weakness of the Schedule 2G test. The heat generated by the burning belt sample is not adequate to simulate a true full-scale situation, i.e., the test fire may not generate sufficient heat to sustain the flame on the sample after removal of the Bunsen burner, whereas the heat in a full-scale fire would be sufficient to cause propagation. Also, the specified 300 fpm air flow tends to blow the flame out with PVC belt, rather than fan it to a higher intensity and faster propagation as would be the case in a full-scale fire.

It is recommended, therefore, that the Schedule 2G flame test be reviewed for its adequacy as a criterion for approval of conveyor belts for use in underground coal mines. Work has been done recently in the German Federal Republic to develop a small scale belt flammability test which produces results closely approximating the results of large scale tests. One such small scale test which has been developed involves a belt test samply 6 cm wide by 1.2 m long in an air flow of 30 m/min and ignited by a 15 minute exposure to a Franke propane gas burner.[7]

9.2 EXTINGUISHING

Generally speaking, automatic sprinklers appears to be the most practical method of fire protection for underground conveyor belt heads. This type system does have limitations, however, where freezing temperatures or inadequate water supplies are a problem. High expansion foam is also a very effective method of extinguishing and its water requirements are minimal. Multipurpose dry chemical extinguishing avoids both the water supply and freezing temperature problems, and is also effective, provided the distribution of powder is adequate.

9.2.1 Automatic Sprinklers

The automatic sprinkler test results indicate that a single overhead branch line with 1/2 inch orifice sprinklers located on 10 foot centers and with actuation temperatures between 200 and 300°F will successfully suppress fires on conveyor belts in most situations. The residual water pressure can be as low as 10 psi. The only exception indicated by the sprinkler tests is where the cooling effect of high ventilation air flows delays sprinkler actuation. Thus, where the air velocity is greater than 250 fpm, the sprinkler actuation temperature should be no higher than 225°F, or as an alternative, the sprinklers should be spaced no greater than 8 feet apart. In areas with low roof clearance, the sprinklers could be positioned at the roof to one side of the conveyor.

The relatively high efficiency of automatic sprinklers in controlling conveyor belt fires appears to be due to its effectiveness in cooling. The ignition temperature of conveyor belting is relatively high, above 600°F for most fire resistant types. For flame propagation to occur, a fairly intense fire is required which will result in preheating adjacent belting downwind from the fire. Sprinklers, even at a low water flow rate, are effective in cooling and suppressing a fire which has already developed, and in preventing propagation, even though the fire may not be completely extinguished.

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[7] Grumbrecht, Klaus. "Investigations on the Flammability of Conveyor Belts in Coal Mines," Gluckauf-Forschungsheft, Vol. 34, No. 4 (August 1973), pp. 130-134. (Translated by Ruth F. Brinkley, U.S. Bureau of Mines. January 1974)

In addition to being highly effective in suppressing conveyor belt fires, automatic sprinkler systems offer other advantages, such as economy, reliability, minimum water demand, and minimum maintenance requirements. Water is usually available at low cost and the installation costs would compare favorably with other systems. Since detection is an integral part of each automatic sprinkler head, no separate detection system is required. Remote indication of system actuation can be provided by a flow switch which would indicate either a fire or other damage to a sprinkler head causing it to open.

Independent actuation of each sprinkler head is also an important advantage in reliability. The system is not dependent on a separate detection system which would be an important link in the reliability chain. Even if one sprinkler were to fail, which would be unlikely in a properly maintained system, only the one sprinkler is lost. Adjacent sprinklers would, in effect, provide back-up protection and still be effective in preventing the spread of fire.

Independent actuation of each sprinkler also means that only those sprinklers in the area of the fire would be actuated, keeping water discharge only to where it is needed. This is an advantage over deluge systems, especially where water supplies might be limited, or excessive water discharge could be damaging to equipment or roof and rib surfaces.

The primary disadvantage of an automatic sprinkler system is that, being a wet pipe system, it would not be practical in freezing temperatures unless sufficient anti-freeze agents could be added to the water supply to prevent freezing. Also, in a wet pipe system, damage to the piping or sprinkler heads could result in release of water unnecessarily, although such a situation would be indicated by actuation of a flow switch indicator.

Where applicable, the recommended system design and installation practice of NFPA Standard No. 13 (National Fire Codes, Vol. 6) should be observed. Included in Standard No. 13 is the provision for pressure gages and system test pipes for periodic checking of the system pressure and flow characteristics. This, along with the other maintenance practices contained in NFPA Standard No. 13A should also be observed.[8] This includes, of course, frequent checking of the piping and sprinkler heads for damage, especially from conveyed material in low roof situations.

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[8] National Fire Protection Association, National Fire Codes, Vol. 6, Sprinklers, Fire Pumps and Water Tanks, (Boston: 1973 - 74)

An approximation of a sprinkler system's flow characteristics can be plotted on the chart shown in Appendix C. Periodic checks of the system should be compared to a reference such as this, to assure that no changes have taken place such as might result from restrictions in the water lines, or from changes in the static water pressure. If a change in static pressure does occur, this chart would then indicate whether or not the water supply still provides adequate protection. This chart can also be useful in determining the adequacy of existing water supplies for new sprinkler systems. Appendix C provides an explanation and an example in the use of this flow characteristics chart.

An alternate procedure for testing a sprinkler system for adequate pressure and flow is to simply replace three sprinkler heads with open deluge type heads. The residual pressure with the system on should be at least 10 psi. Three sprinkler heads are considered adequate, since all successful extinguishments in this test program were achieved with no more than two sprinklers being actuated.

The system shut-off valve provided for this or any other purpose should be equipped with some means of clearly indicating when it is turned off, as recommended by NFPA Standard No. 13, to prevent its being inadvertently left in the off position. If left off, not only is the extinguishing system lost, neither would there be any indication of a fire if a flow switch is used to provide this indication.

9.2.2 High Expansion Foam

High expansion foam is a highly effective method of extinguishing belt-head fires, having extinguished all of the test fires, even though ignition of more than two overhead boards occurred in some before the extinguishment took place. Once the foam reaches the fire, extinguishment is quick and complete.

The primary advantage of high expansion foam is its low water requirements, making it an attractive system where water is not readily available and storage is necessary. Adequate protection can be provided with as little as 50 to 100 gallons of water.

As recommended by the Bureau of Mines Coal Mine Safety Inspection Manual for Underground Mines, the foam generation unit should be located on the intake air side of the belt head to be protected, so as to take advantage of the ventilation air flow in driving the foam toward the location of the fire, and also to avoid contaminated air from entering the foam generation unit, since foam quality and generation efficiency would be reduced by smoke contaminated air.[9]

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[9] U.S. Bureau of Mines, Coal Mine Safety Inspection Manual for Underground Mines, (September, 1972) Section 75.1101-5.

A foam generation rate of five minutes to envelop 50 feet of fire-resistant belt would seem to be adequate in extinguishing a belt head fire, although this rate did result in more than two overhead softwood boards igniting in actual tests. The test conducted at this rate with PVC-3 belting resulted in ignition of five overhead softwood boards, with extinguishment being achieved four minutes after actuation of the foam generator (six minutes after ignition). Thus, while the foam may not reach the fire as quickly as with other agents, extinguishment is rapid and complete when it does.

This same foam generation rate would also be adequate in extinguishing a belt head fire involving the FR-2 type nonfire-retardant belt, since fire on this belt appears to propagate no more rapidly than on the fire-resistant belts tested. A generalization on the adequacy of this generation rate for all nonfire-resistant belting should not be made, however, until a thorough evaluation of the burning properties of all nonfire-resistant belting used in coal mines is made.

Operation of the foam generator for 25 minutes, as required by regulation, provides ample assurance of extinguishment in the belt head area. Theoretically, if 50 feet of belt is enveloped in 5 minutes, 250 feet would be enveloped in 25 minutes. This is, of course, a function of foam stability and breakdown caused by the fire, and to a greater extent, location of the generator unit and the configuration of the belt entry. It is possible that a high ratio foam would envelop the generator itself within 25 minutes and "recycle" a portion of the foam, thereby reducing the effective generation rate and thus reduce the total distance of foam travel within the 25 minute period. A disadvantage of high expansion foam in situations where there is no alternate path for ventilation air is the fact that the foam will not reach the roof. Thus ignition that might occur on the roof might not be extinguished, and might even be fanned by the higher air flow in the space between the foam and the roof, due to the orifice effect of the foam plug.

9.2.3 Multi-Purpose Dry Powder

Extinguishment with a dry powder system is rapid, being achieved within the discharge time of the powder. Discharge time, by regulation, must be less than one minute.[10] Another major advantage of dry powder is the fact that no special provisions are necessary for use in freezing temperatures.

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[10] "Rules and Regulations, Section 75.1101-19", Federal Register, Vol. 35, No. 226 (November 20, 1970), p. 17920.

A most important consideration in the design of a dry powder system is belt surface coverage. Each system must be individually designed to insure that powder will impinge on all belt surfaces likely to become involved in a fire. No areas should be shielded by decking, conveyor structure members, side enclosures, or any other items that would interfere with the powder distribution. If any fire were to survive the powder discharge in such areas, or reignition were to occur, the fire is likely to regain intensity and result in propagation. To insure proper distribution, system installation should include a trial discharge and subsequent inspection of the powder distribution on the belt surfaces.

In the tests conducted, all belt fires except those involving decking on the conveyor were extinguished with 75 pounds of powder or less, thus indicating that system requirements currently specified by regulation are satisfactory, assuming the discharge pattern is adequate. The system specified for fire-resistant belting calls for 125 pounds of powder discharged in the belt drive and take-up areas and over 50 feet of adjacent belt. Due to the greater equipment density and additional belt layers in the take-up and drive sections of the conveyor, powder discharge should be from both sides of the conveyor, whereas discharge from only one side would be adequate when only two belt layers are involved. Assuming approximately equal discharge from each nozzle, this would result in approximately twice as much powder being discharged in the take-up and drive sections per unit length of conveyor than in the less congested areas. Nozzle discharge is also an important consideration, requiring proper selection of nozzle orifice sizes and placement of restrictors to achieve a fairly uniform discharge from each nozzle. Or the discharge may want to be varied to provide more powder where greater protection is needed.

Since dry powder is fast acting, 50 feet of belt coverage would probably be adequate for nonfire-resistant belting as well, especially if the nonfire-resistant belting used in this program is representative of the burning properties of other nonfire-resistant belting in use in coal mines. Even if fire were to develop more rapidly on some belt types, detection would be correspondingly more rapid and still enable extinguishment before any appreciable propagation has occurred.

In addition to the disadvantage of powder distribution being so critical, powder has little cooling effect and is more likely to result in reignition than with water based extinguishants. Reignition could be due to the same ignition source which caused the fire initially, with heating from the fire itself also being a factor. Other disadvantages are the greater vulnerability of the discharge nozzles to damage from material spilling from the belt, and the discomfort to personnel who might be in the area during discharge.

9.3 DETECTION

Of the various types of detection devices included in this program, the thermal point and thermal continuous types appear to be most practical for use in underground conveyor belt protection. Most are adequately sensitive for early detection of fire, their ability to withstand the mine environment is good, and most are economical to use, although the continuous types would be somewhat more expensive due to the amount of continuous detector required.

Products of combustion type detectors tend to be less practical due to the problem of dust, while the range of optical type detectors appears to be too limited to be practical, especially in view of the relatively high cost of the detector heads.

9.3.1 Thermal Point Type Detectors

The locations of thermal point type detectors currently required by regulation for belt head protection are over the discharge pulley and the belt drive.[11] These locations should also provide coverage for any other potential fire hazard in the belt head area, such as a hydraulic take-up, or electrical equipment.

As seen from the thermal point detector test data, there can be significant differences in sensitivity between the various detectors available. These variations bear some correlation to the maximum detection spacings recommended in UL and FM approval listings. It is therefore recommended that all potential fire hazards in the belt head area be protected by detectors spaced in accordance with the recommendations of UL, FM, or any other acceptable testing laboratory.

A practical method of providing such detection coverage would be to place detectors over possible fire hazards nearest either end of the belt head zone for which automatic fire extinguishing coverage is provided. Additional detectors would then be located between these two as necessary to comply with the detector spacing recommendations. In many instances a detector over the belt drive and another over the discharge pulley will provide such coverage. No detectors that will cause automatic actuation of the belt head extinguishing system should be located outside the area of coverage of the extinguishing system.

The alarm temperature ratings of thermal point type detectors should be within the ranges recommended by Underwriters' Laboratories. I.e., where the

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[11] "Rules and Regulations, Section 75.1103-4 (a) (1), "Federal Register, Vol. 37, No. 159 (August 16, 1972), p. 16545.

maximum ambient temperature does not exceed 100°F, the detector rating should be between 135°F and 165°F. For maximum ambient temperatures between 100°F and 150°F, the detector rating should be between 175°F and 225°F.[12]

Rate-of-rise type detectors which are sensitive to pressure change, could be actuated by sudden drops in pressure, such as could result from turn-on or turn-off of ventilation systems. One of the rate-of-rise detectors tested is designed to actuate due to a pressure decrease of 3 to 4 inches of H_2O per minute. The pressure change sensitivity of rate-of-rise detectors should, therefore, be considered in their use in mine areas where such pressure changes could occur.

With regard to the spacings for thermal point type detectors along conveyor belt runs, the current requirement for detectors located every 125 feet (50 ft where the ventilation air flow is greater than 100 fpm or the conveyor belt is not fire-resistant) would appear to be adequate in view of the fact that automatic extinguishment is not a requirement. Based on the actuation data taken in the belt fire tests, a fire of the same rate of development and intensity as the test fire would result in detection by most thermal point type detectors within two to four minutes. Faster detection resulting from detectors spaced any closer would be relatively insignificant in relation to the time required for a fire crew to reach the area.

9.3.2 Thermal Continuous Type Detectors

Thermal continuous detectors, like the thermal point types, provide good resistance to the mine environment, and most provide good sensitivity to belt fires.

In most instances a suitable location for continuous detectors would be along the roof over the center of the conveyor. In some instances, however, the roof condition might not be suitable for detector mounting, such as where roof cavities exist. Here the detector could still be located over the conveyor, but a canopy or other type heat collector would be desirable to assure that hot gasses from a belt fire would impinge on the detector. A primary consideration in the selection of any thermal detector location is impingement of hot gasses from the fire on the detector, the objective being to enable the earliest detection possible.

As with point type detectors, only the detector segments located within the belt head area should trigger the automatic belt head extinguishing system.

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[12] Underwriters' Laboratories, Fire Protection Equipment List (January, 1974) p. 118.

There appears to be a significant variation in sensitivity in different types of thermal continuous detectors. Of the detectors included in the test program, the two with metal outer surfaces provided the fastest response, averaging 11 and 7 seconds respectively in the fire tests. The pressurized thermoplastic hose type detector, rated at approximately the same temperature, responded in an average of 2 minutes. Thus, detector sensitivity is an important consideration in the selection of an alarm temperature rating. For the pressurized thermoplastic hose type detector, the maximum temperature setting that should be used is 170°F, which is the maximum temperature rating recommended by UL for thermal detectors where the maximum ambient temperature ranges up to 100°F.[13] The more sensitive continuous detectors would be suitable at higher temperature ratings, however, since a continuous type detector would provide continuous coverage along the conveyor. The two metal sheathed detectors tested would be suitable with temperature ratings of up to 300°F, since this is only slightly above the actuation temperature of 286°F automatic sprinklers, and would result in actuation of the automatic extinguishing system at approximately the same time, or possibly ahead (due to greater sensitivity) of the 286°F automatic sprinkler.

Comparison to a 286°F sprinkler head would appear to be a suitable method for evaluating the sensitivity for continuous type detectors. I.e., when subjected to the same heat source, the continuous detector should provide an alarm at the same time or before actuation of a 286°F automatic sprinkler.

None of the three detectors tested as continuous types are listed by UL or FM. The TC-1 continuous detector which was tested as a point type detector, is listed by both UL and FM as a continuous type detector, however.

9.3.3 Products of Combustion Type Detectors

As mentioned, a serious disadvantage of products of combustion type detectors, one that limits the practicality of their use in underground coal mines, is their vulnerability to dust. Both the ionization and the photoelectric types displayed sensitivity to dust such as might result from rock dusting operations, and both types indicated possible changes in sensitivity or malfunctioning due to exposure to coal dust over a period of time. Such vulnerability might be expected since the air sampling portion of these type detectors must, by nature, be open and exposed to dust. In many models, the electrical circuitry is also exposed and vulnerable to airborne dust.

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[13] Ibid.

Another disadvantage of products of combustion detectors for use in belt head fire protection is the fact that smoke or other combustion products from any source upwind of the detector could cause actuation of the belt head extinguishing system, even though the source may not be within the area of coverage of the extinguishing system.

The test data did reveal, however, that product of combustion type detectors could provide early detection, especially in instance of a smoldering condition preceding actual flames. The spacing of detectors along belt runs would depend to a large extent on the ventilation rate in the belt entry. A rule of thumb for determining the spacing required for products of combustion detectors is to multiply the ventilation rate by the time within which the detector should operate. In order to detect a fire of the same magnitude as the belt fires used in this program, within the same time as thermal point detectors spaced 125 ft. apart, detection should take place within approximately four minutes. Thus, with a ventilation rate of 100 fpm, for example, the detectors should be spaced no more than 400 ft. apart. In neutral or low speed air products of combustion detectors need not be spaced closer than 250 ft.

9.3.4 CCTV

The use of closed circuit television for detection of visible smoke is of limited practicality. To be equivalent to thermal detectors, the spacing requirement for the cameras would be the same as for the products of combustion type detectors. The cost of such a system to provide fire detection alone would be economically unfeasible. In addition, the monitors would require constant monitoring and introduces the element of human error.

With regard to belt head protection, the TV camera would have to be at the down wind end of the belt head section, or the entire belt head area would have to be within the field of view of the camera. Also, the belt head extinguishing system would not be automatic, but would have to be actuated remotely by the person viewing the monitor.

Dust accumulation, however, does not appear to be a serious problem with CCTV as it is with the products of combustion type detectors.

9.3.5 Carbon Monoxide Detection

Since carbon monoxide is a product of combustion, some of the characteristics and limitations of combustion type detectors would also apply to carbon monoxide detection. For example, the spacing requirements for carbon monoxide detectors would be the same, or possibly closer than for products of combustion detectors, depending on the sensitivity setting of the carbon monoxide detectors. Also, with regard to belt head protection, isolation of the fire location to within the range of the belt head extinguishing system could be a problem. Also, dust accumulation over long periods of time would be a problem with most CO detectors.

9.3.6 Optical Type Detectors

The effective range of UV and IR type detectors appears to be too limited to be practical in conveyor belt application. The normal sensitivity settings of most optical type detectors would limit their effective range to approximately 20 ft. Even then, detection would not be completely reliable due to the possibility of flames being shielded from the detector by conveyor belting, conveyor structure, or other objects in the area.

Another disadvantage of optical type detectors, especially most IR types, is their sensitivity to light sources other than flames. The UV types are generally sensitive to electrical arcing, and the IR types also tend to be sensitive to vehicle head lamps and even cap lamps.

An advantage of optical type detection is fast response to flame, although this would be more advantageous in explosion suppression applications than in belt head fire suppression. Belt head fires could smolder and burn in concealed areas before coming into view of an optical detector. Some IR types, however, would be capable of detecting heat energy in the infra-red spectrum range which would be emitted by smoldering and concealed fires.

Generally speaking, however, the relatively close spacings that would be necessary, coupled with the relatively high cost of most optical detectors, would make optical type detection economically unfeasible in most conveyor belt applications.

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APPENDIX A

SUMMARY LISTING OF PRELIMINARY TESTS

Test No.	Date	Belt	Ignition Method	Air Flow (fpm)	Max. Gallery Surface Temp.	Propagation	Remarks
1	3-1-73	Used non-fire resistant rubber, Make FR-1	On top belt in take-up, with 30" square preheat plate at 450°F for 15 min. Plate withdrawn to allow ignition.	200	650°F	5 Ft.	Fire died down and was manually extinguished at 18 min.
2	3-6-73	Used neoprene, Make N-1	Same as Test No. 1, with 23% volatile coal dust on belt.	400	125°F	None	Required 6 minutes for belt to ignite. Flame intensity remained low throughout test. Extinguished manually at 21 min.
3	3-6-73	Used neoprene, Make N-2	Same as Test No. 1.	400	90°F	None	Fire intensity remained low and went out at 24 min. Belt had moisture in the carcass which steamed off during the test.
4	3-6-73	Used PVC, Make PVC-2	Same as Test No. 1.	200	115°F	None	Gas burner burned hole in belt, then the belt fire went out after 10 minutes, with gas burner still on.
5	3-7-73	Used rubber, Make R-1 (fire-resistant)	Same as Test No. 1.	200	155°F	None	Fire went out at 23 minutes.
6	3-12-73	Used neoprene, Make N-2	On top belt in take-up, with 5' x 30" preheat plate and 2 preheat burners. One burner turned off, and preheat plate removed when 450°F reached.	200	115°F	None	Same belt as Test No. 3. Sample heated to 250°F for 5 hours, and 160°F for 65 hours to drive out moisture. Fire went out at 20 minutes.

Test No.	Date	Belt	Ignition Method	Air Flow (fpm)	Max. Gallery Surface Temp.	Propagation	Remarks
7	3-14-73	Used neoprene, Make N-2	On top belt in take-up, with grease/coal dust mixture coating on 5' preheated section of belt. 5' x 30" preheat plate with 2 burners. One burner turned off and plate removed after 450°F held for 15 minutes.	200	510°F	5 Ft. (on coated area)	Belt preheated at 275°F for 16 hours to drive out moisture. Fire died down after coated area burned. Manually extinguished at 32 minutes.
8	4-11-73	New PVC, Make PVC-3	On top belt in take-up, with 5' x 30" preheat plate and 2 burners. 450°F preheat held for 15 minutes, then one burner turned off and plate removed to allow ignition.	200	>1000°F	Entire 10' Test Section	The 10' test section spliced into the conveyor system burned in 15 minutes, but adjacent used neoprene belt did not burn.
9	4-18-73	New PVC, Make PVC-1	Same as Test No. 8.	200	630°F	7 Ft.	Preheated area ignited and burned rapidly, but fire then died down and burned with low intensity until extinguished manually at 11 minutes.
10	4-19-73	New rubber (SBR), Make R-2 (fire-resistant) 20 inches wide	Same as Test No. 8.	200	430°F	8 Ft.	Belt supported combustion, but burned slowly. Fire was extinguished manually at 19 minutes.
11	4-23-73	New rubber (SBR), Make R-2 (fire-resistant) 20 inches wide	Same as Test No. 8.	200	200°F	3 Ft.	Belt tension was high, causing belt to snap away from the point of ignition when it broke. Loose belt then placed over gas burner, resulting in 200°F temperature on gallery ceiling. (Test witnessed by Bureau of Mines representatives.)

Test No.	Date	Belt	Ignition Method	Air Flow (fpm)	Max. Gallery Surface Temp.	Propagation	Remarks
12	4-23-73	New PVC, Make PVC-3	Same as Test No. 8. Belt samples were also put on lower belt layers, below the ignited sample (four layers total).	200	>1000°F	Entire 10' Test Section	Fire extinguished at 11 minutes to prevent fire damage to gallery. (Test witnessed by Bureau of Mines representatives.)
13	4-24-73	New rubber (SBR), Make R-3 (fire-resistant)	5' of belt preheated to 450 to 500°F for 15 min. Belt ignited with gas ignition torch on top surface of top belt in take-up.	200	630°F	10 Ft. (to end of test sample)	Fire went out at 17 minutes, after burning to the end of the test sample. Ignition was slow (5 min.)
14	5-1-73	New PVC, Make PVC-3	Same as Test No. 13.	200	850°F	10 Ft. (to end of test sample)	Fire extinguished manually at 20 minutes. Intensity had decreased after preheated section burned.
15	5-4-73	Used PVC, Make PVC-2	23% volatile coal dust on belt and take-up frame. 5' preheated to 450-500°F for 15 min. Belt ignited with gas ignition torch on top surface of bottom (4th) belt layer in take-up.	200	>1000°F	9 Ft.	Fire burned slowly for 10 minutes, increased to its maximum intensity, then died down again. Extinguished at 15 minutes.
16	5-14-73	New PVC, Make PVC-1	23% volatile coal dust on preheat plate and 2 top belt layers. 5' preheated to 450 to 500°F with 2 gas burners, then ignited on top surface of 2nd belt layer in take-up.	125	645°F	60 Ft.	Belt ignited quickly. Fire burned to end of 20 Ft. test sections, plus 40 Ft. of used PVC belt. Extinguished by hand at 55 minutes.
17	5-17-73	Used PVC, Make PVC-2	Same as Test No. 16, except with 3 burners under preheat plate.	125	425°F	12 Ft.	Fire went out at 50 minutes.

Test No.	Date	Belt	Ignition Method	Air Flow (fpm)	Max. Gallery Surface Temp.	Propagation	Remarks
18	5-21-73	Used PVC, Make PVC-2	Same as Test No. 16.	125	275°F	9 Ft.	Fire went out at 90 minutes.
19	5-21-73	Used PVC, Make PVC-2	Same as Test No. 16, except with 3 burners under preheat plate, and 1/2 to 1 inch gap between preheat plate and preheated belt section.	125	175°F	1 Ft.	Ignition torch left on for 30 minutes. Fire went out after torch was turned off.
20	5-24-73	New rubber (SBR) Make R-3 (fire-resistant)	Same as Test No. 16.	125	560°F	7 Ft.	Fire went out at 30 minutes.
21	5-31-73	New PVC, Make PVC-1	Same as Test No. 16, except without coal dust.	125	600°F (momentary spike to 835°F)	To end of 20 Ft. test section	Belt ignited quickly. Fire extinguished at 25 minutes, so as not to damage belt beyond the test section.
22	6-1-73	New PVC, Make PVC-1	Same as Test No. 16, except with 37% volatile coal dust.	125	400°F	To end of 20 Ft. test section	Fire extinguished at 46 minutes so as not to damage belt beyond the test section.
23	6-4-73	New PVC, Make PVC-1	Mineral oil and 37% volatile coal dust on preheat plate and 2 top belt layers. 5' preheated to 450 to 500°F with 3 gas burners, then ignited on top surface of 2nd belt layer in take-up. 1/2 to 1 inch gap between preheat plate and preheated belt section.	125	565°F (momentary spike to 710°F)	10 Ft.	Belt ignited quickly. Fire went out at 57 minutes.

Test No.	Date	Belt	Ignition Method	Air Flow (fpm)	Max. Gallery Surface Temp.	Propagation	Remarks
24	6-11-73	New PVC, Make PVC-1	Same as Test No. 16, except with mineral oil in place of coal dust on preheat plate and 5 Ft. of 2 top belt layers.	125	675°F (Spikes to 875°F and 985°F)	To end of 20 Ft. test section	Belt ignited quickly and spread to end of test section when high air flow applied to clear smoke for viewing purposes. Fire extinguished at 11 minutes.
25	6-12-73	New PVC, Make PVC-1	Same as Test No. 16, except with mineral oil in place of coal dust, and belt ignited on top surface of 3rd belt layer in take-up.	125	725°F (Spikes to 1000°F)	11 Ft.	Top surface of test belt charred for 2 additional feet when high air flow applied to clear smoke for viewing purposes. Fire went out at 55 minutes.
26	6-13-73	Used PVC, Make PVC-5	Same as Test No. 16, except with mineral oil in place of coal dust on preheat plate and 12.5 Ft. of 2 top belts.	125	300°F (Spike to 435°F)	1 Ft.	Belt slow to ignite (3-1/2 minutes). Fire went out at 15 minutes.
27	6-14-73	New PVC, Make PVC-1	Same as Test No. 26.	125	720°F (Spike to 985°F)	10 Ft.	Top surface of belt charred for 2 additional feet (as in Test No. 25). Fire went out at 45 minutes.
28	6-15-73	New PVC, Make PVC-1	Mineral oil on preheat plate and 12.5 Ft. of 2 top belt layers. 5' preheated to 500°F for 15 minutes with 2 burners. Belt ignited on top surface of 2nd belt layer in take-up.	125	800°F (Spike to 1000°F)	To end of 20 Ft. test section	Belt ignited quickly; 5' preheated section aflame in 1 minute. Entire test sections consumed in 15 minutes. Fire extinguished at 15 minutes.
29	6-22-73	Used PVC, Make PVC-4	Same as Test No. 28, except preheat held for 20 minutes.	125	450°F	10 Ft.	Fire developed quickly in preheated section, but with fairly low intensity Fire went out at 25 minutes.
30	6-22-73	New PVC, Make PVC-1	Same as Test No. 28	125	250°F	10 Ft.	Same as Test No. 29. Fire went out at 20 minutes.

Test No.	Date	Belt	Ignition Method	Air Flow (fpm)	Max. Gallery Surface Temp.	Propagation	Remarks
31	6-25-73	New PVC, Make PVC-3	Same as Test No. 28.	125	>1000°F	To end of 20 Ft. test section	Preheated section engulfed within one minute, gallery roof temperature reached 1000°F in 2 minutes. Roof timbers burning at 4 minutes. Fire spread to end of test sections in 5 minutes. Fire extinguished at 5 minutes.
32	6-27-73	New PVC, Make PVC-3	Same as Test No. 28.	125	>1000°F	To end of 20 Ft. test section	Similar to Test No. 31. Fire extinguished at 6-1/2 minutes. Tests 32 through 36 conducted to evaluate repeatability.
33	6-28-73	New PVC, Make PVC-3	Same as Test No. 28.	125	>1000°F	To end of 20 Ft. test section	Similar to Test No. 31. Fire extinguished at 5-1/2 minutes.
34	6-29-73	New PVC, Make PVC-3	Same as Test No. 28.	125	>1000°F	To end of 20 Ft. test section	This test was conducted during rainy weather. Due to heavy rain preceeding the test, the gallery floor was very wet at the point where the burning belt normally falls to the floor. This slowed the fire down considerably until it had propagated past this point. The fire was extinguished at 23 minutes.
35	7-2-73	New PVC, Make PVC-3	Same as Test No. 28.	125	>1000°F	To end of 20 Ft. test section	Results similar to Test No. 31. Fire extinguished at 6-1/2 minutes.
36	7-11-73	New PVC, Make PVC-3	Same as Test No. 28.	125	>1000°F	To end of 20 Ft. test section	Results similar to Test No. 31. Fire extinguished at 4 minutes.

Test No.	Date	Belt	Ignition Method	Air Flow (fpm)	Max. Gallery Surface Temp.	Propagation	Remarks
37	7-11-73	New PVC, Make PVC-3	Same as Test No. 28.	Neutral	1000°F	To end of 20 Ft. test section	Propagation was considerably slower than with tests at 125 fpm air. Dense smoke travelled extensively in both directions away from the fire. Fire extinguished at 25 minutes.
38	7-12-73	New PVC, Make PVC-3	Same as Test No. 28.	350	1000°F	To end of 20 Ft. test section	Fire propagated to end of 20 Ft. test section in 3 minutes. Fire extinguished at 3 minutes.
76	8-27-73	New non-fire resistent rubber, Make FR-2	Same as Test No. 28.	125	1000°F	To end of 20 Ft. test section	Fire propagation slower than with new PVC belt, Make PVC-3. Fire extinguished at 14 minutes.
78	8-28-73	New non-fire resistent rubber, Make FR-2	Same as Test No. 28, except without mineral oil.	125	1000°F	To end of 20 Ft. test section	Propagation slightly faster than in Test No. 73. Fire extinguished at 10-1/2 minutes.

APPENDIX B

EVALUATION TESTS

TABLE B-I - Automatic Sprinklers
TABLE B-II - High Expansion Foam
TABLE B-III - ABC Dry Powder

TABLE B-I

TESTS WITH AUTOMATIC WATER SPRINKERS

Test No.	Date	Test Configuration	Automatic Sprinklers			Sprinkler No. (a)	Actuation Time	Time to Extinguish	Charred Boards	Remarks
			Temp.	Spacing	Pressure					
39	7/30/73	Standard (b)	286°F	10'	10 psi	2	1.5 min.	See Remarks	No Data	Fire controlled, but not extinguished. Water turned off after 14 minutes, allowing fire to rekindle.
						1	Could not be ascertained			
40	7/31/73	Standard	286	8	10	2	1.1	10 min.	No Data	
41	7/31/73	Standard	286	10	50	2	1.2	10	2	
						1	4.0	10	2	
42	8/1/73	Standard	286	10	10	2	1.2	See Remarks	0	Fire controlled, but not extinguished. Water turned off after 10 minutes, allowing fire to rekindle. Fire completely extinguished within one minute when water was turned back on.

NOTES: (a) Sprinklers are numbered consecutively starting with No. 1 on the upwind side of the ignition zone, and all others on the downwind side. Sprinklers No. 1 and 2 are spaced equidistant from the ignition point for 8, 10 and 12 foot spacings, and 5 ft and 10 ft respectively from the ignition point for 15 foot spacings.

(b) "Standard" test configuration consists of PVC-3 (fire-resistant) belting, 3 ft roof clearance over the top belt, no deck on the conveyor, and 125 fpm ventilation air flow. These conditions apply unless otherwise noted.

TABLE B-I (Continued)

Test No.	Date	Test Configuration	Automatic Sprinklers			Sprinkler No.	Actuation Time	Time to Extinguish	Charred Boards	Remarks
			Temp.	Spacing	Pressure					
43	8/2/73	Standard	286°F	10'	20 psi	2	1.0 min.	10 min.	0	
						1	4.2			
44	8/2/73	Standard	286	12	20	2	0.8	See Remarks	0	Fire controlled, but not extinguished. Water turned off after 10 minutes, allowing fire to rekindle.
45	8/3/73	Standard	286	12	30	2	1.0	10	0	
46	8/3/73	Standard	286	15	50	2	2.3	10	4	Excessive ignition of adjacent combustibles occurred.
						1	3.3			
47	8/6/73	Standard	212	10	10	2	0.75	10	0	
						1	3.75			
48	8/6/73	Standard	212	12	10	2	0.6	See Remarks	3	Excessive ignition of adjacent combustibles. Fire rekindled after 10 minute application of water.
						1	2.55			
49	8/7/73	Standard	212	12	20	2	0.6	See Remarks	0	Fire controlled, but not extinguished. Water turned off after 10 minutes, allowing fire to rekindle.
						1	3.25			
50	8/7/73	Standard	212	15	20	2	1.55	19 min.		
						1	2.4		1	

TABLE B-I (Continued)

Test No.	Date	Test Configuration	Automatic Sprinklers			Sprinkler No.	Actuation Time	Time to Extinguish	Charred Boards	Remarks
			Temp.	Spacing	Pressure					
51	8/8/73	Standard	165°F	12'	10 psi	2 1 4 3	0.7 min. 2.25 7.25 7.7	15 min.	0	All sprinklers actuated, althoug fire did not progress beyond sprinkler No. 2.
52	8/8/73	Standard	165	8	10	2	0.5	25	0	
53	8/9/73	Standard	165	10	10	2 1 4 3	0.4 1.9 2.9 Could not ascertain	20	1	All sprinklers actuated, althoug fire did not progress beyond sprinkler No. 2.
54	8/9/73	Standard	165	10	20	2	0.5	50	0	
55	8/10/73	Deck	-	-	-	-	-	-	3	Pilot test to check effect of deck on test fire.
56	8/10/73	Deck	286	10	10	2	4.5	76	0	
57	8/13/73	Deck	286	15	10	1	11.4	31	2	
58	8/14/73	1.5 ft roof clearance	280	10	10	2 1	1.1 4.0	22	2	
59	8/15/73	Neutral air flow	280	10	10	2	2.5	<9	2	Dense smoke interferred with observation of test.
60	8/15/73	1.5 ft roof clearance	280	12	10	2 1	2.1 min. 2.3	15 min.	3	Excessive ignition of adjacent combustibles occurred.
61	8/16/73	Neutral air flow	280	12	10	1	2.5	37	2	

TABLE B-I (Continued)

Test No.	Date	Test Configuration	Automatic Sprinklers			Sprinkler No.	Actuation Time	Time to Extinguish	Charred Boards	Remarks
			Temp.	Spacing	Pressure					
62	8/16/73	1.5 ft roof clearance	280°F	12'	30 psi	1 2	2.5 min. 5.0	18 min.	3	Excessive ignition of adjacent combustibles occurred.
63	8/16/73	Neutral air flow	280	15	10	1 2	6.5 21.25	27	4	Excessive ignition of adjacent combustibles occurred.
64	8/16/73	1.5 ft roof clearance	212	12	10	2 1 3	1.0 1.9 5.0	24	3	Excessive ignition of adjacent combustibles occurred.
65	8/20/73	350 fpm air flow	280	10	10	3	3.2	19	4	Invalid test results. Sprinkler No. 2 was defective and failed to actuate. Mfgr. advised failure was due to improper assembly during manufacture. Excessive ignition of adjacent combustibles occurred.
66	8/20/73	1.5 ft roof clearance	212	12	20	2 1	1.1 4.0	17	3	Excessive ignition of adjacent combustibles occurred.
67	8/21/73	350 fpm air flow	280	10	10	2 3	2.25 3.0	See Remarks	3	Re-run of test No. 65. Excessive ignition of adjacent combustibles occurred. Fire burned to end of belt test sections and was extinguished with hand hose at 21 minutes.
68	8/21/73	1.5 ft roof clearance	212	12	50	2 1	1.25 3.75	19	3	Excessive ignition of adjacent combustibles occurred.

TABLE B-I (Continued)

Test No.	Date	Test Configuration	Automatic Sprinklers			Sprinkler No.	Actuation Time	Time to Extinguish	Charred Boards	Remarks
			Temp.	Spacing	Pressure					
69	8/22/73	350 fpm air flow	280°F	8'	10 psi	2	1.8 min.	15 min.	2	
70	8/22/73	1.5 ft roof clearance	165	10	50	2 3 1	0.75 1.3 5.75	18	3	Excessive ignition of adjacent combustibles occurred.
71	8/23/73	350 fpm air flow	280	10	50	2 3	2.3 2.5	15	3	Excessive ignition of adjacent combustibles occurred.
72	8/23/73	350 fpm air flow	212	10	10	3 2	2.1 2.3	10	2	
73	8/24/73	FR-2 Belt	280	10	10	2	2.1	28	2	
74	8/24/73	350 fpm air flow	212	12	10	2 3	2.5 2.8	20	2	
75	8/27/73	FR-2 Belt	280	12	10	2 1	1.4 2.9	8	2	
76	8/27/73	FR-2 Belt	-	-	-	-	-	14	No Data	Pilot test to evaluate test fire using FR-2 belt.
77	8/28/73	FR-2 Belt	280	15	10	2 1	2.7 3.0	12	2	

TABLE B-I (Continued)

Test No.	Date	Test Configuration	Automatic Sprinklers			Sprinkler No.	Actuation Time	Time to Extinguish	Charred Boards	Remarks
			Temp.	Spacing	Pressure					
78	8/28/73	FR-2 Belt	-	-	-	-	-	11	No Data	Pilot test to evaluate effect of mineral oil on fire with FR-2 belt.
79	8/29/73	FR-2 Belt	212°F	15'	10 psi	2 1	1.9 min. 2.6	14 min.	2	
80	8/30/73	FR-2 Belt, deck	280	15	10	2 1	7.8 11.4	30	4	Excessive ignition of adjacent combustibles occurred.
81	8/30/73	FR-2 Belt 350 fpm air flow	280	15	10	2	2.6	See Remarks	3	Excessive ignition of adjacent combustibles occurred. Fire extinguished manually at 7 minutes due to high intensity to prevent damage to test gallery.
82	8/31/73	FR-2 Belt, deck	280	12	10	1 2	7.7 7.8	16	3	Excessive ignition of adjacent combustibles occurred.
83	8/31/73	FR-2 Belt 350 fpm air flow	280	12	10	2	1.3	17	0	

TABLE B-I (Continued)

Test No.	Date	Test Configuration	Automatic Sprinklers			Sprinkler No.	Actuation Time	Time to Extinguish	Charred Boards	Remarks
			Temp.	Spacing	Pressure					
84	9/4/73	FR-2 Belt, deck	280°F	10 ft	10 psi	2 1	9.5 min 12.5 min	15 min	0	
85	9/4/73	Deck, 350 fpm air flow	280	10	10	2	17.25	42	2	
86	9/5/73	FR-2 Belt, deck	280	12	10	2	21	35	3	Repeat of test #82 with deck secured more tightly
87	9/5/73	Deck, 350 fpm air flow	280	12	10	2	18	30	2	
88	9/6/73	FR-2 Belt, deck, 350 fpm air flow	280	12	10	2	22	35	4	
89	9/6/73	Deck, 350 fpm air flow	280	15	10	2	19.5	34	3	
90	9/7/73	FR-2 Belt, deck, 350 fpm air flow	280	10	10	2	14	21	2	
91	9/10/73	FR-2 Belt, deck, 350 fpm air flow	280	12	20	2	14.5	23	4	

TABLE B-I (Continued)

Test No.	Date	Test Configuration	Automatic Sprinklers			Sprinkler No.	Actuation Time	Time to Extinguish	Charred Boards	Remarks
			Temp.	Spacing	Pressure					
111	10/3/73	Standard	Open	10	10	See remarks				Test conducted to check effectiveness of CCTV system in detecting presence of smoke in gallery. Deluge type sprinkler system, manually operated, was used.
112	10/5/73	350 fpm air flow	280	10	10	2 3	2.0 2.2	See Remarks	3	Test conducted for filming. Test void due to fire developing in area under sprinkler #1. Sprinkler #1 was removed to protect photography lights.
113	10/5/73	350 fpm air flow	280	10	10	2 3	2.3 2.7	15 min	0	Repeat of test #112, for purposes of filming.
115	10/17/73	1.5 ft roof clearance	212	10	10	2 1	0.75 16.2	30 min	1	Fire moved upwind slowly until #1 sprinkler was actuated.
116	10/17/73	1.5 ft roof clearance	165	8	10	2 1	0.3 2.7	10 min	1	

TABLE B-II

TESTS WITH HIGH EXPANSION FOAM

Test No.	Date	Test Configuration	Foam Rate (a)	Actuation Time	Time to Extinguish (from ignition)	Boards Charred	Remarks
92	9/10/73	Standard (b)	50 ft of belt enveloped in 5 min.	2 min. (manually actuated)	6 min	5	Foam generator discharge chute positioned 28 ft upwind from conveyor discharge pulley.
93	9/11/73	Standard	50 ft of belt enveloped in 2.5 min.	2 min.	4 min	3	
94	9/12/73	Standard	50 ft of belt enveloped in 2.5 min.	2 min	4 min	3	Test void due to malfunction of foam generator. Repeat of test #93 with foam discharge chute positioned at conveyor discharge pulley.
95	9/13/73	Standard	50 ft of belt enveloped in 2.0 min.	2 min	3 min	2	Repeat of test #94.
96	9/14/73	350 fpm air flow	50 ft of belt enveloped in 2.0 min.	2 min	5.5	3	High air flow tended to blow foam past the ignition area without enveloping the flame.

NOTES: (a) Foam Characteristics:
Expansion Ratio: 1000:1
Stability: Not more than 25% drainage in 25 minutes

(b) "Standard" test configuration consists of PVC-3 (fire resistant) belting, 3 ft roof clearance over the top belt, no deck on the conveyor, and 125 fpm ventilation air flow. These conditions apply unless otherwise noted.

TABLE B-II

TESTS WITH HIGH EXPANSION FOAM (CONT)

Test No.	Date	Test Configuration	Foam Rate (1)	Actuation Time	Time to Extinguish (from ignition)	Boards Charred	Remarks
97	9/17/73	350 fpm air flow	50 ft of belt enveloped in 2.0 min.	2 min	4.5 min	3	Repeat of test #96, with foam discharge chute positioned directly. over conveyor discharge pulley (position to one side in previous tests) in attempt to prevent foam from blowing past ignition zone.
98	9/17/73	FR-2 belt	50 ft of belt enveloped in 2.5 min.	2 min	3.5 min	4	Test results in doubt, due to malfunction in foam generator engine
99	9/18/73	Deck	50 ft of belt enveloped in 2.0 min.	12.5	14 min	0	
100	9/19/73	FR-2 belt	50 ft of belt enveloped in 2.0 min.	2 min	3 min	2	Repeat of test #98.

TABLE B-III

TESTS WITH ABC DRY POWDER

Test No.	Date	Test Configuration	Lbs powder at 350 psi	Actuation Time	Time to Extinguish (from ignition)	Boards Charred	Remarks
101	9/19/73	Standard	75 lbs	1 minute	1.3 min.	0	
102	9/21/73	Standard	50 lbs	3.5	3.8	2	Actuation delayed until belt burned thru.
103	9/21/73	Standard	25	2.0	See Remarks		Fire not completely extinguished. Repropagation of fire occurred.
104	9/24/73	350 fpm air flow	50	2.75	3.0	0	
105	9/24/73	FR-2 belt	50	3.25	See Remarks		Fire repropagated.
106	9/24/73	FR-2 belt	75	2.2	2.5		Data on # of boards charred not taken, since this has no bearing on effectiveness of dry powder extinguishant.
107	9/25/73	Deck	50	25.5	See Remarks		Fire not completely extinguished, repropagated.
108	9/25/73	Deck, 350 fpm air flow	50	7	See Remarks		Fire not completely extinguished, repropagated.
109	9/26/73]	Standard	50	3.5	3.8		Repeat of test #102 to check repeatability.
110	9/26/73	Deck	100	8.5	See Remarks		Fire not completely extinguished, repropagated.
114	10/5/73	350 fpm air flow	50	2	See Remarks		Tests conducted for purposes of filming. Fire repropagated after powder system had actuated.

APPENDIX C

WATER FLOW CHARACTERISTICS CHART[1]

The flow characteristics of a water supply for a new sprinkler system can be most easily obtained by equipping a 1-inch water meter with a pressure gauge at its inlet and a gate valve at its discharge. The water meter assembly is connected to the water supply, water to the meter is turned on, and the water pressure read with the gate valve closed. The gate valve is then opened until the pressure gauge falls to 25 psi (or to the minimum pressure with the valve open). The water flow is obtained by timed readings of the water meter. These two points are then plotted on the chart, i.e., static pressure at 0 gpm flow rate, and the open valve pressure at the recorded flow rate. The open valve pressure should be reduced slightly to allow for pressure drop in the sprinkler system piping, strainer, and valve. This drop would be in the order of 5 psi at an open valve pressure of 25 psi. The two points are joined by a straight line and then the available flow rate at any other pressure can be picked off the plotted line. Knowing the flow characteristics of sprinkler heads, the allowable number of heads for the system can be determined.

The approximate flow characteristics for a standard 1/2 inch orifice sprinkler are as follows:

Pressure at Sprinkler	Discharge Rate
10 psi	18 gpm
15 psi	22 gpm
20 psi	25 gpm
25 psi	28 gpm
35 psi	34 gpm
50 psi	41 gpm
65 psi	45 gpm

Thus, for the system plotted in Figure C-1, the maximum number of sprinklers allowable to maintain a residual (flow) pressure of not less than 20 psi, would be six (6 x 25 gpm = 150 gpm at 20 psi).

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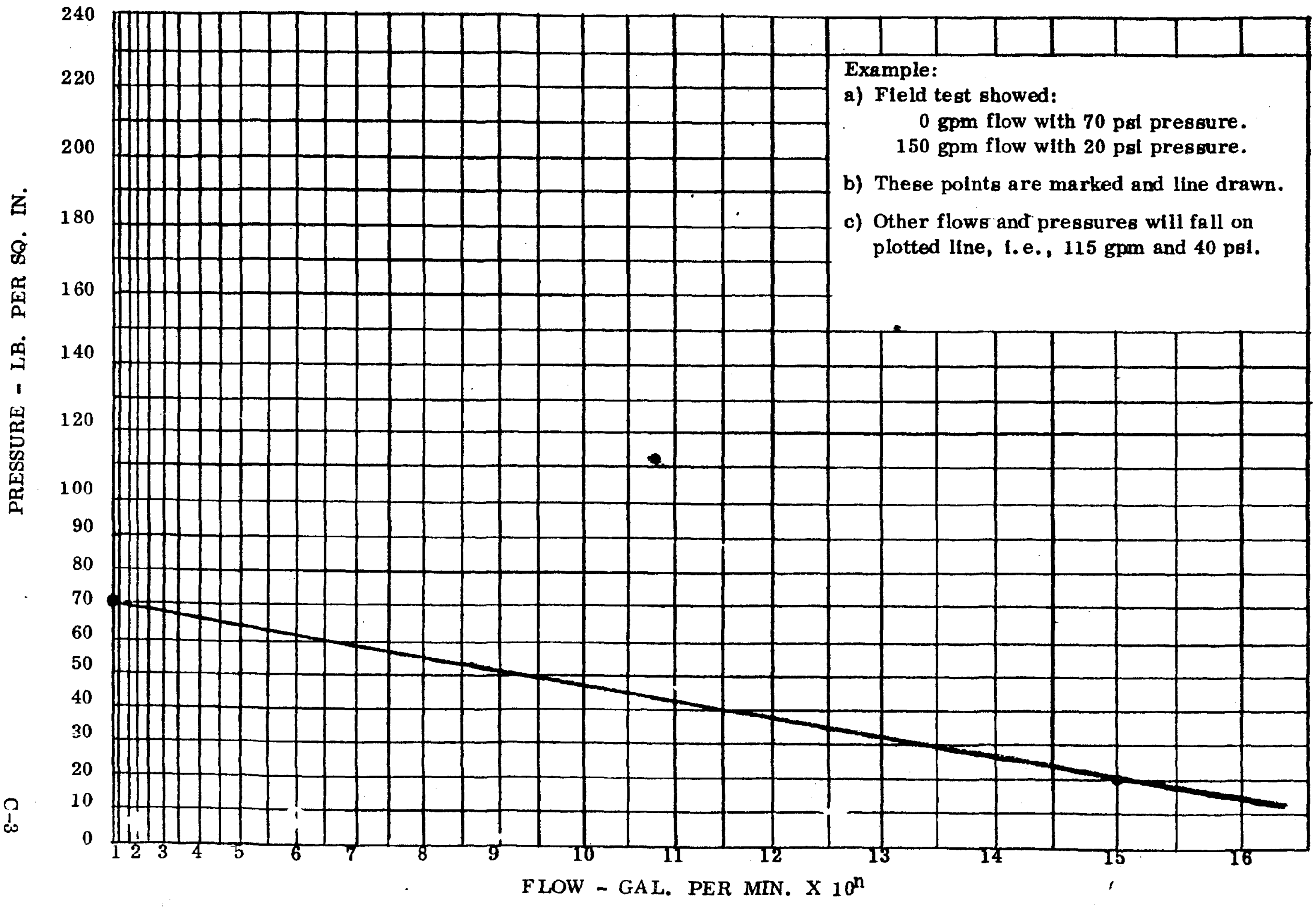
[1] Information source: "Fire Protection and Fire Fighting in Coal Mines", Paper presented to the Tenth Annual Mining Industry Technical Conference, IEEE Mining Industry Committee, April 1, 1969, by W. B. Jamison.

For periodic checking of a sprinkler system, the system test pipe recommended in NFPA Standard No. 13 may be used. The test pipe should be at the end of the sprinkler system, so that the entire system, including the flow switch, is checked. The test pipe would include a valve, a pressure gage, and a known orifice, such as an opened sprinkler head. Or the system could be tested merely by replacing the last sprinkler with an open sprinkler. The pressure gauge is read with the water flowing through the open sprinkler, and the flow rate can then be determined from the known sprinkler flow characteristics. In the example shown in Figure C-1, the residual pressure with one open sprinkler would be approximately 65 psi (45 gpm flow rate).

The plotted point of pressure vs. flow rate should fall on the line plotted for the system. If it falls below the line, the system has been degraded, probably due either to a drop in static pressure, or to a restriction in the water lines. Any line restriction should, of course, be cleared. If the change is due to a drop in static pressure, a new line should be plotted to determine if the water supply is still adequate.



Example:

a) Field test showed:
  0 gpm flow with 70 psi pressure.
  150 gpm flow with 20 psi pressure.

b) These points are marked and line drawn.

c) Other flows and pressures will fall on plotted line, i.e., 115 gpm and 40 psi.

Figure C-1