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UNITED STATES DEPARTMENT OF THE INTERIOR

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CONTENTS



ILLUSTRATIONS



TABLES

## UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

| | | | |
|---|---|---|---|
| Btu/lb | British thermal unit per pound | lb | pound |
| Btu/min | British thermal unit per minute | min | minute |
| °C | degree Celsius | mL | milliliter |
| ft | foot | pct | percent |
| ft/min | foot per minute | pt | pint |
| in | inch | qt | quart |
| kW | kilowatt | s | second |
| L | liter | wt | weight |

# FIRE TESTS OF RIGID PLASTIC VENTILATION DUCTS

By F. J. Perzak,[1] C. P. Lazzara,[2] and T. A. Kubala[3]

ABSTRACT

The Bureau of Mines conducted a flammability study of plastic ventilation ducts. Six rigid 16-in-diam fiberglass-reinforced plastic ducts from five manufacturers were examined using laboratory-scale, large-scale, and full-scale fire tests. The laboratory-scale tests included the American Society for Testing and Materials E162 radiant panel test, the E2863 oxygen index test, and the standardized small-scale flammability test ($S^3FT$) developed by the Mine Safety and Health Administration (MSHA), U.S. Department of Labor, and replicated by the Bureau of Mines. Ten-foot lengths of the same ducts were also subjected to a large-scale vertical fire test, and 20- to 30-ft lengths were tested in a full-scale in-mine fire test at the Bureau's Lake Lynn Laboratory mine.

The data from the laboratory-scale radiant panel test and oxygen index test indicated that the ducts were fire-resistant. However, five of the six ducts failed the $S^3FT$ and vertical fire tests, and four of the ducts failed the full-scale in-mine tests with flame propagation rates that ranged from 3 to 10 ft/min. The results indicate the need for improved fire-resistant plastic ducts. The good agreement between the $S^3FT$ results and the vertical and full-scale tests show that the $S^3FT$ provides a good indication of the flammability of fiberglass-reinforced plastic ducting under realistic fire conditions.

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## INTRODUCTION

Fiberglass-reinforced plastic (FRP) ducts or tubes are used in mines for ventilation purposes where corrosion resistance, mechanical strength, and cost are the primary considerations. A fire involving FRP ducting, however, with the attendant smoke and gaseous products, can be a severe hazard to personnel in underground mines or other confined areas. A fire in a duct can feed back to itself well over 50 pct of the combustion heat as demonstrated by fires in wood-lined ducts (1)[4] and is thus more severe than a fire on a flat surface. Nevertheless, FRP ducting is currently used to line chimneys (2), as stack liners for industrial operations (3), and in vertical shafts (4). FRP ducts 3 ft in diam and 30 ft long were fire tested in the vertical configuration by Factory Mutual Research Corp. Flaming combustion over the full sample length occurred after 1 min of exposure to a moderate heptane pool fire under the duct (3). Although mine fires involving FRP ducts have been few, two fatalities occurred in 1971 in a metal mine when ducting was accidentally ignited by a cutting torch and about 400 ft of ducting burned (5).

The ability of a plastic material to resist ignition and subsequent flame propagation is usually estimated by laborabory-scale tests. However, few of these tests consider the end use of the material or provide a realistic appraisal of the flammability behavior under full-scale fire conditions. Federal regulations for ventilation tubing (6) require materials approved for underground coal mines to have a flame spread index of 25 or less, based on the American Society for Testing and Materials (ASTM) E162 radiant panel test or E84 tunnel test. The "25 or less," value was previously thought "to provide a reasonably safe condition" (7) for ducts in coal mines. There are no Federal fire-resistance standards for ventilation tubing in metal and nonmetal mines. A voluntary procedure for acceptance of FRP ventilation tubing (8) for underground coal mines recently issued by MSHA includes a standardized small-scale fire test ($S^3FT$). In this test, 4-ft-long by 16-in-diam duct samples are ignited by a gas burner in a horizontal tunnel, and the time for flame extinguishment and the extent of burning were determined.

In this study, 16-in-diam FRP ducts from five manufacturers were subjected to laboratory-scale, large-scale, and full-scale fire tests to evaluate their fire resistance and to compare test results. The laboratory-scale tests included the ASTM E162 radiant panel test (9), the E2863 oxygen index test (10), and the $S^3FT$ developed by MSHA. The MSHA Approval and Certification Center also tested the ducts in its $S^3FT$ appartus. Ten-foot lengths of the same ducts were subjected to a simple large-scale vertical fire test, and 20- to 30-ft duct samples were tested in a full-scale in-mine fire test at the Bureau's Lake Lynn Laboratory mine (11). The test procedures and results are presented in this report.

## ACKNOWLEDGMENTS

The authors wish to acknowledge the contributions of personnel from the MSHA Industrial Safety Division for conducting the ASTM E162 radiant panel tests and the MSHA Approval and Certification Center for conducting the tests in the MSHA $S^3FT$ apparatus.

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

## TEST SAMPLES

Fiberglass-reinforced plastic ventilation tubing is routinely manufactured in 10- and 20-ft lengths with diameters ranging from 12 to 60 in. Oval configurations are also available. For this study, a sufficient number of 16-in-diam duct 10 ft long was purchased from five manufacturers so that all the fire tests could be conducted with the same sample batch. The 16-in-diam ducting is a common size used in mines. Table 1 gives a description of the tubing. In two of the in-mine tests, 12-in-diam and 20-in-diam ducting from the same source as duct samples C and D were also used for comparison.

All the ducts were accepted by MSHA for use in underground coal mines based on a flame spread index of 25 or less by the ASTM E162 test method. Sample A had heavier and thicker walls than did the other ducts and was manufactured with a highly fire-resistant resin containing a high loading of aluminum trihydrate. The major fire retardant in the other ducts was approximately 1 to 3 wt pct antimony oxide. The heating values are an indication of the maximum combustible content of the duct and vary with the percentage of the components, such as the ratio of fiberglass to plastic resin. Ducts C and D were different batches from the same source; duct D contained a higher concentration of fire retardant.

## EXPERIMENTAL FIRE TESTS AND RESULTS

### ASTM FIRE TESTS

The ASTM laboratory-scale tests were the ASTM E162 radiant panel (9) and the E2863 oxygen index (10). In this study, the tests were applied to composite plastic materials; i.e., rigid ducts. These tests provide an estimate of the response of the duct sample to heat and flame under controlled conditions and are not recommended to assess the fire hazards of a material under realistic fire conditions.

The samples for the ASTM tests were cut from 16-in-diam ducts. The samples for

TABLE 1. - Description of 16-in-diameter, 10-ft-long ducts

| Duct | Generic description | Total weight, lb | Wall thickness, in | Heating value,[2] Btu/lb |
|---|---|---|---|---|
| A... | Plastic resin[1]........<br>Glass fiber filler....<br>Aluminum trihydrate... | 58 | 5/32 | 4,000 |
| B... | Plastic resin.........<br>Fiberglass ribbon.....<br>Aluminum trihydrate...<br>Antimony oxide........ | 32 | 1/16 | 3,450 |
| C... | Plastic resin.........<br>Fiberglass ribbon.....<br>Antimony oxide........ | 37 | 3/32 | 4,530 |
| D... | ...do................. | 37 | 3/32 | 3,930 |
| E... | ...do................. | 36 | 3/32 | 2,920 |
| F... | ...do................. | 41 | 1/8 | 3,600 |

[1]The plastic resin is a thermosetting polyester resin.
[2]Determined by ASTM D2015, Gross Calorific Value of Solid Fuel by the Adiabatic Bomb Calorimeter (12).

the oxygen index test were the thickness of the duct wall and 0.5 in wide by 6 in long. The samples for the radiant panel test were 6 in wide by 18 in long. Any effects due to the slight curvature of the samples were negligible.

The oxygen index and radiant panel test results for the duct samples are given in table 2. The limiting oxygen index is the lowest value of the ratio of oxygen to oxygen plus nitrogen that will support candle-like combustion of the plastic sample: The higher the value, the greater the fire resistance of the duct sample. The individual values of the limiting oxygen values ranged from 27.1 to 44.7 and were within ±0.5 for each sample. The average value for all the samples is 37, which signifies that the material contains fire retardants.

The flame spread index from the radiant panel test is calculated from the flame spread rate and heat evolution factor. A low flame spread index signifies a high fire resistance. The values range from 5±3 to 42±20, with an average of 14.7 for all the samples. The large variances in the flame spread indices are mainly due to experimental difficulties in determining the flame-spread rate and the heat evolution factor for these inhomogenous composite materials. A flame spread index of 25 or less is required for the ducts to be permitted in underground coal mines. All the ducts except duct C were well within this requirement level.

The fire-resistance rankings of the duct samples based on their limiting oxygen and flame spread indices are in excellent agreement. The Spearman ranking coefficient was 0.96, where 1.0 signifies a perfect correlation and 0.0 no correlation.

TABLE 2. - Results of laboratory-scale ASTM tests

| Duct | Limiting oxygen index | Flame spread index |
|---|---|---|
| A...... | 44.7 | 5± 3 |
| B...... | 33.0 | 15± 5 |
| C...... | 27.1 | 42±20 |
| D...... | 36.3 | 9± 6 |
| E...... | 37.9 | 11± 9 |
| F...... | 43.4 | 7±10 |

## STANDARDIZED SMALL-SCALE FLAMMABILITY TEST ($S^3FT$)

### Description

The $S^3FT$ apparatus consists of an insulated ventilated tunnel, 5 ft long by 3.5 ft high and 2.5 ft wide. A 4-ft-long by 16-in-diam duct sample without flaired ends or support rings is suspended horizontally in the center of the tunnel. The ignition source is a 12-jet gas burner that delivers 26 kW over a 4-in-wide by 12-in-long area (12-in-high flame). The burner is positioned beneath the lower edge of the duct sample so that two-thirds of the burner flame is under the tubing and the remaining one-third of the flame is allowed to lick into the inside of the tubing. The burner flame is held in contact with the duct for exactly 1 min. The tunnel ventilation flow is controlled to give 0 or 125 ft/min air velocity over the suspended duct sample. Figure 1 shows the ignition of a 16-in-diam duct sample. The insert shows the duct flame 2 min after the removal of the burner.

A total of six duct sections are tested in two groups of 3, at 0 and 125 ft/min airflow. A sample fails if (1) flame propagates 4 ft (total length) in any single test, or (2) the average time duration of the burning duct measured after burner removal exceeds 1 min at either air velocity, or (3) the time duration of the burning duct after burner removal exceeds 2 min for any one of the six samples tested.

### Results

The same five FRP ducts were subjected to the $S^3FT$ by the Bureau and by MSHA'S Approval and Certification Center to compare the reproducibility of the results between laboratories. A sixth duct, sample C, was tested only by MSHA. Table 3 gives the average flame duration after removal of the burner for each sample and whether the duct passed or failed. For some ducts, a complete series of six tests was not completed when failure was assured.

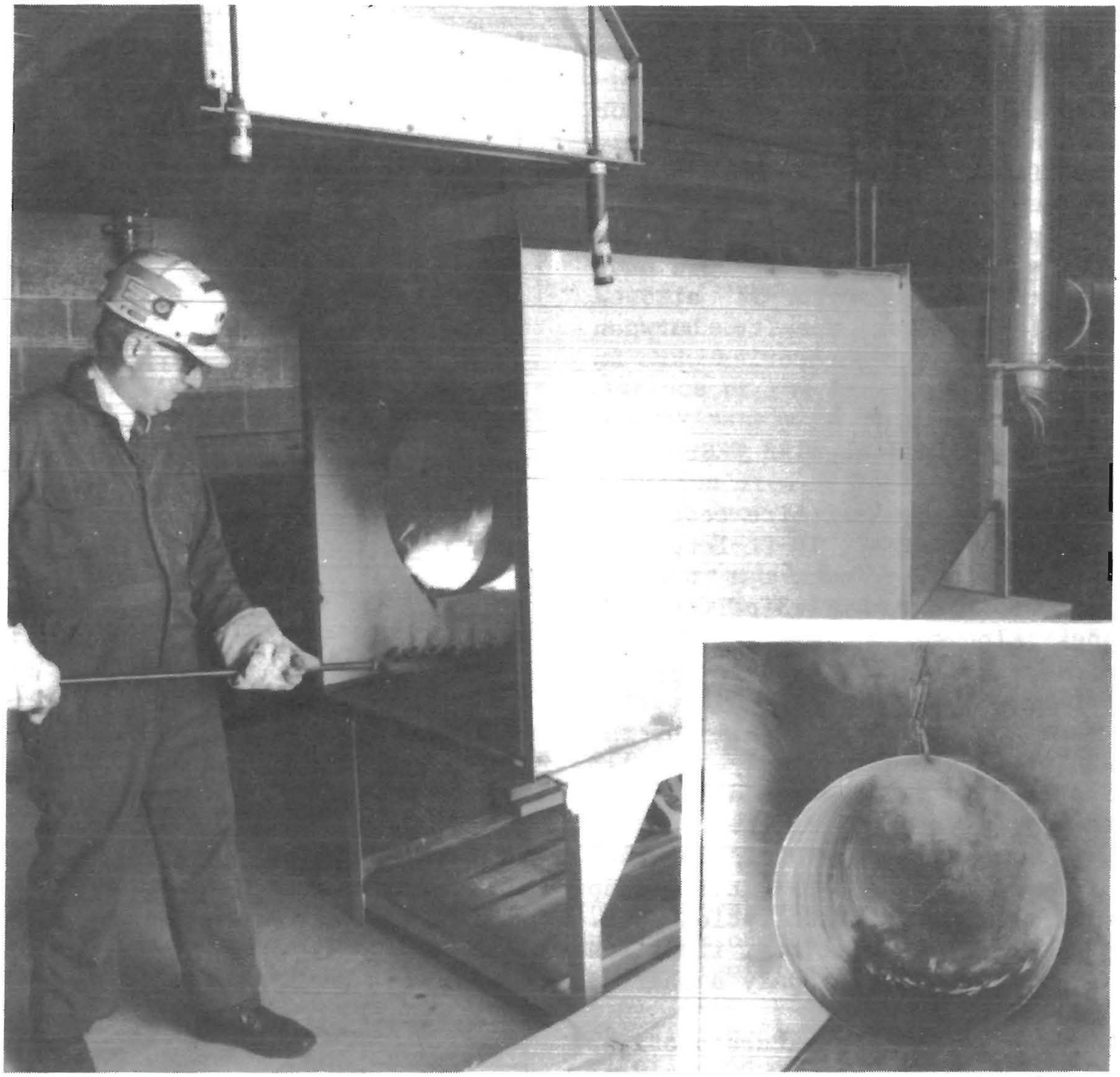

FIGURE 1.—Ignition of 16-in-diam FRP duct in the standardized small-scale flammability test apparatus. Insert shows flaming duct 2 min after burner removal.

TABLE 3. - Standardized small-scale flammability test ($S^3FT$)

| Duct | Average MSHA flame time, min | Average Bureau flame time, min | Fail or pass |
|---|---|---|---|
| A.......... | [1]0.02 | [1]0.03 | Pass. |
| B.......... | [2]>3 | [2]>3 | Fail. |
| C.......... | >3 | NA | Do. |
| D.......... | [2]>3 | [2]>3 | Do. |
| E.......... | [3]2.8 ±0.9 | [3]4 ±0.5 | Do. |
| F.......... | [3]7 ±4 | [2]>3 | Do. |

NA Not available.
[1]Sample self-extinguished within 2 s after burner removal.
[2]Sample was extinguished 3 min after burner removal and would have burned the full 4 ft in most cases.
[3]Sample self-extinguished. The value following the ± sign is the standard deviation using all 6 tests at both flows.

Only duct A passed the $S^3FT$ by self-extinguishing as soon as the burner was removed. Ducts E and F self-extinguished; however, their average time for "after burning" exceeded 1 min and they failed by criteria 2 and 3. Ducts B, C, and D failed by all three criteria and were purposely extinguished because of excessive smoking. They would have burned their full length if allowed to continue. The test results between the Bureau and MSHA laboratories were in excellent agreement.

## LARGE-SCALE VERTICAL FIRE TEST

The large-scale vertical fire test consisted of a 16-in-diam, 10-ft-long duct suspended vertically over a nominal 22-in-diam pool fire of 1.3 pt (600 mL) of heptane. In a few tests, the duct was instrumented with 20 gage type K thermocouples with their beads inserted about 2 in from the inside wall of the duct. The pool fire burned for about 1.3 min. Blank trials using steel ducts gave temperatures at the top of the duct as high as 1,000° C in about 40 s. Figure 2 shows a schematic view of the test setup for a 10-ft-section of ventilation duct. A duct failed the vertical test if it was consumed by flames leaving only a charred fiberglass carcass.

Figure 3 shows the temperature profiles at three locations for duct C. The data record starts at zero time; however, the igniter began at about 0.4 min. The sudden drop in temperature about 0.8 min is probably due to the flame bursting through the walls. The heptane igniter was out at about 1 min. Figure 4 shows the vertical fire test for duct C. Panel *A* shows the duct at ignition. After 30 s, the exterior surface is engulfed in flames (panel *B*) and at about 1 min (panel *C*) the duct collapses leaving fiberglass ribbons (panel *D*). Approximately 22 pct of the weight of the original duct was consumed in about 2 min or less, with the generation of large quantities of black, acrid smoke. Several tests were made with duct C at a 45° angle with similar results as the vertical test. The combustible products were not analyzed.

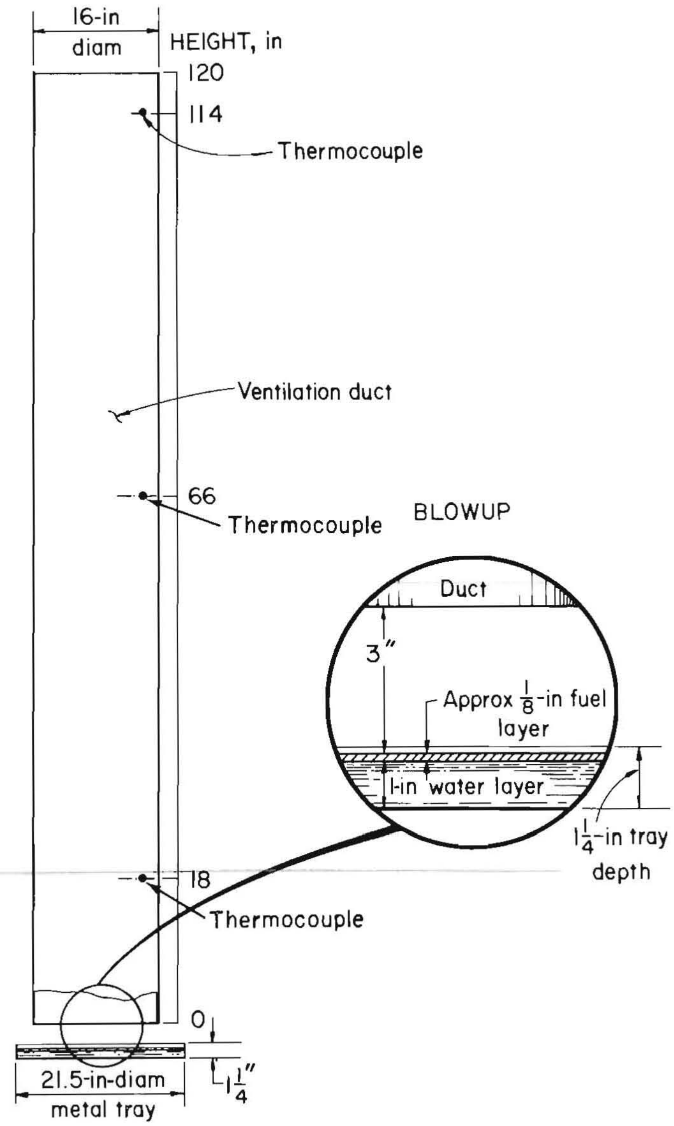


**FIGURE 2.—Schematic view of setup for large-scale vertical fire test of ventilation duct.**

Ducts A and C were tested simultaneously in the vertical configuration. Figure 5 shows the vertical fire test for ducts A and C. Panel *A* shows the experimental setup before ignition with duct C on the left side. Panels *B* and *C* show the ducts at 76 s and 90 s, respectively, after ignition. Duct A on the right was virtually undamaged, but duct C was consumed by the flames. Ducts B, D, E, and F behaved similarly to duct C and failed the vertical fire test. Duct A was the only one that passed the test. For the five ducts that burned, weight losses varied from 22 pct for duct C to 34 pct for duct

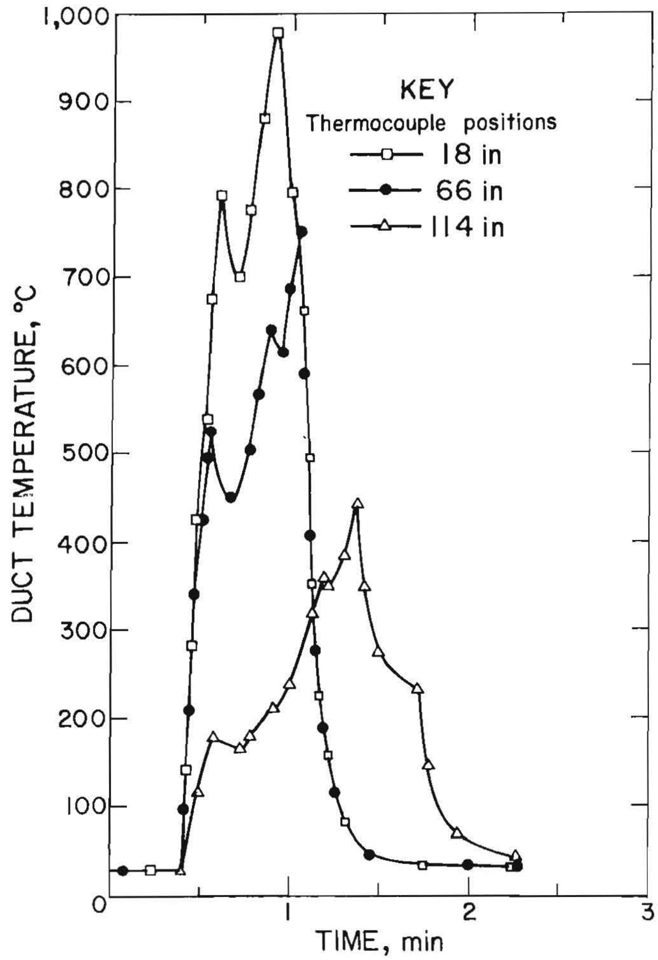


**FIGURE 3.—Temperatures inside duct C during vertical fire test. Thermocouple heights measured from bottom.**

E. The weight loss for duct A was negligible and this duct was retested many times with little damage.

The results of a large-scale vertical fire test of duct F are described in detail in table 4 where the temperatures at a position 6 in from the top inside the duct and comments of significant events are given. Figure 6 shows the vertical fire test of duct F.

## FULL-SCALE IN-MINE FIRE TESTS

### Description

The in-mine duct fire tests were designed to provide data on the flammability behavior of the ducts under full-scale conditions. The tests were performed in a 7-ft-high by 19-ft-wide horizontal entry in the Lake Lynn Laboratory mine (11). The air ventilation in the entry was approximately 190 ft/min. Two or three 10-ft sections of the duct were suspended horizontally to form a nominal 20-ft or 30-ft run. When a 20-ft run of a particular duct was tested, a 10-ft section of highly fire resistant duct A was attached on the end to obtain a total 30 ft length. The ducts were supported every 5 ft by a looped chain attached to an overhead chain. The outer surface of the first duct was positioned approximately 1 ft from a metal shield protecting the mine roof and rib in the ignition area. The distance of the following duct sections from the rock mine ribs and roof ranged from 1.25 to 2 ft. The suspended duct run was instrumented with type K thermocouples. The thermocouples were positioned at 2-ft intervals, starting at the upstream edge of the first duct, with their measuring junctions just inside the duct walls. The thermocouples were connected to a data acquisition system that recorded the thermocouple readings every 6 s during a test. Video recordings and photographs were made for most of the tests by cameras located near the floor about 25 ft upstream of the ignition region.

The ignition source was a 22-in-diam tray fire of 2.1 qt (2 L) of heptane. The 1.5-in-deep tray was supported by a metal stand and contained a layer of water on which the heptane was floated. The heptane pool was positioned 4 in below the upstream edge of the duct run with the end of the duct over the center of the pool. In this position, the pool flames impinged on the outer and inner duct surfaces. The heptane pool was remotely ignited by an electric match and burned about 3.5 min with a heat output of about 16,300 Btu/min. Figure 7 shows the test arrangement for the in-mine tests.

For this study, a duct was considered to fail the in-mine test if it ignited and flames propagated to the end of the second duct section, a distance of about 20 ft. The extent of flame propagation was determined by the thermocouples, video recordings, and examination of the ducting after the test. Flame spread

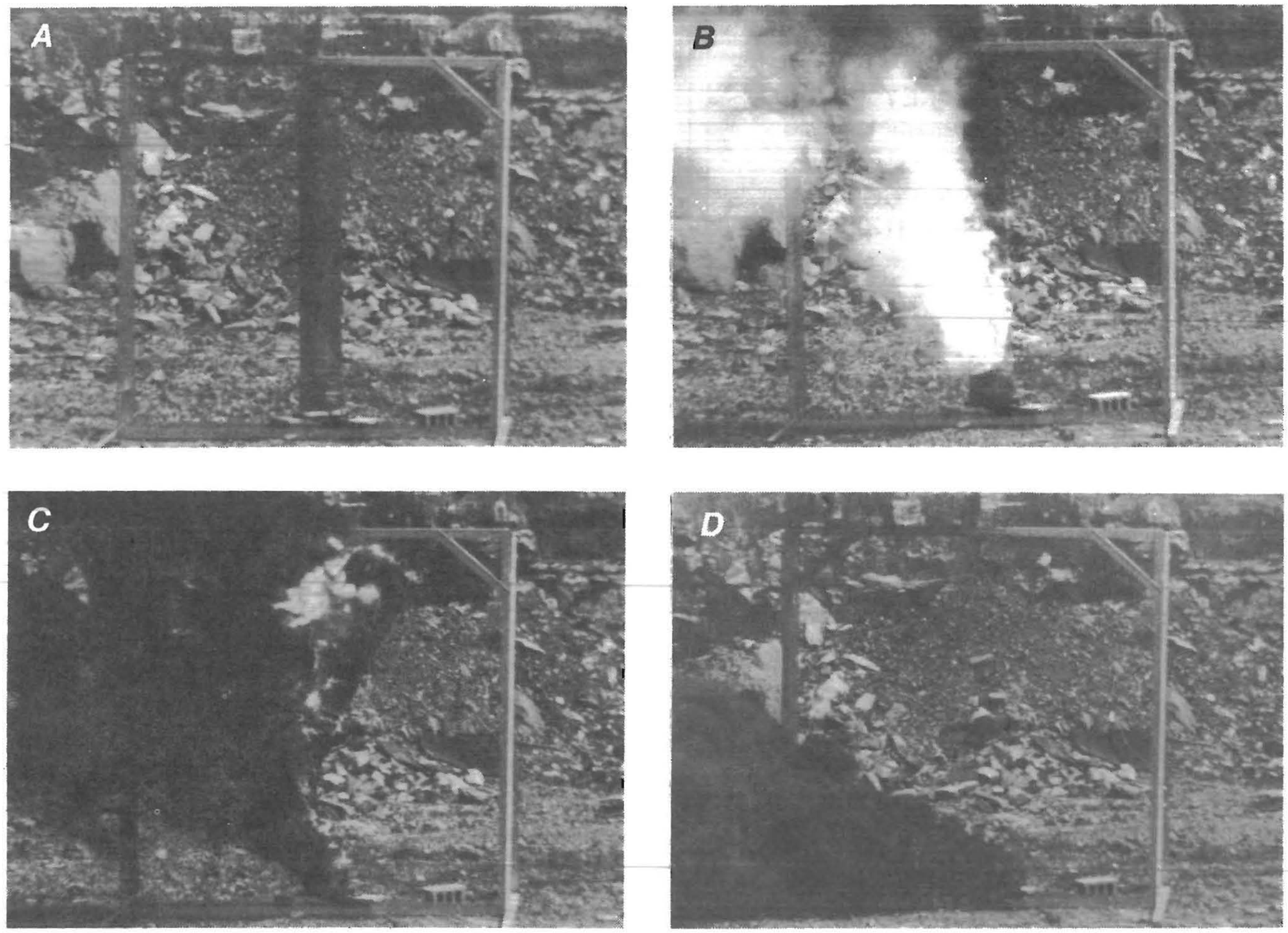


**FIGURE 4.—Vertical fire test of duct C. *A*, At ignition; *B*, flashover of exterior surface at 30 s; *C*, collapse of duct at about 1 min; *D*, smoking remains at 1.8 min.**

rates were also determined from the time-temperature profiles obtained by the thermocouples. The percentage weight loss of the duct samples was calculated from the weight before and after the test.

## Results

Ducts A and D passed the in-mine fire test. Duct A was not ignited by the heptane pool fire and only charred in the region where the pool flames contacted the duct. Duct D was ignited by the pool fire, but flames propagated only 8 ft along the top surface close to the roof. Figure 8 shows the in-mine fire test for duct D. Panel *A* shows duct D prior to the test, and panels *B* and *C* show the ducting at 2.5 and 3.5 min, respectively, after the heptane pool fire was ignited. The duct continued to burn along the top surface for an-another few minutes before the flames

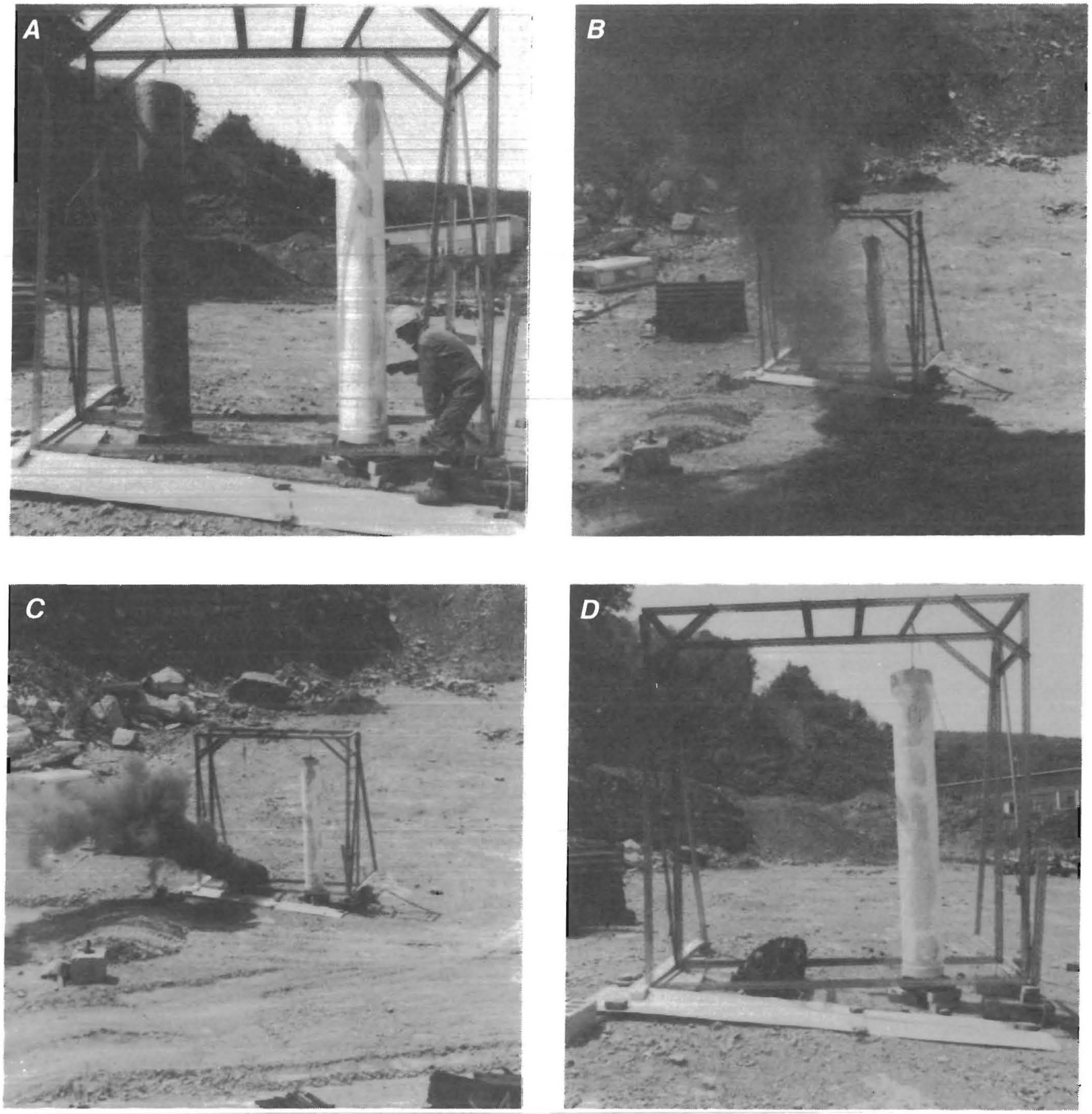


**FIGURE 5.—Vertical fire test of duct A (right side) and duct C. *A*, Before ignition; *B*, 76 s after ignition; *C*, 90 s after ignition; *D*, after test.**

TABLE 4. - Vertical fire test sequence of events for duct F

| Time, min:s | Temperature,[1] °C | Event |
|---|---|---|
| 0:00 | 20 | Tray fire ignition (figure 6, panel *A*). |
| :34 | 470 | Black smoke from top of duct. |
| :38 | 500 | Flame 4 ft high inside duct. |
| :42 | 570 | White smoke 2 ft up from bottom on outside of duct. |
| :46 | 600 | Heavy black smoke from top of duct. |
| :57 | 942 | Flame in smoke at top of duct (figure 6, panel *B*). |
| 1:07 | 985 | Duct sways and sags, smoke and flame from top. |
| 1:16 | 1,010 | Continuous flame from top of duct. |
| 1:21 | 860 | Tray fire out. |
| 1:48 | 670 | Entire duct on fire. Heavy black smoke (figure 6, panel *C*). |
| 2:49 | 320 | Duct burning at top 2 ft and bottom 1 ft. |
| 3:28 | 210 | Flame at top rim, and 2 ft down from top. |
| 4:03 | 70 | No flame visible (figure 6, panel *D*). |

[1]Thermocouple located inside duct, 6 in from top.

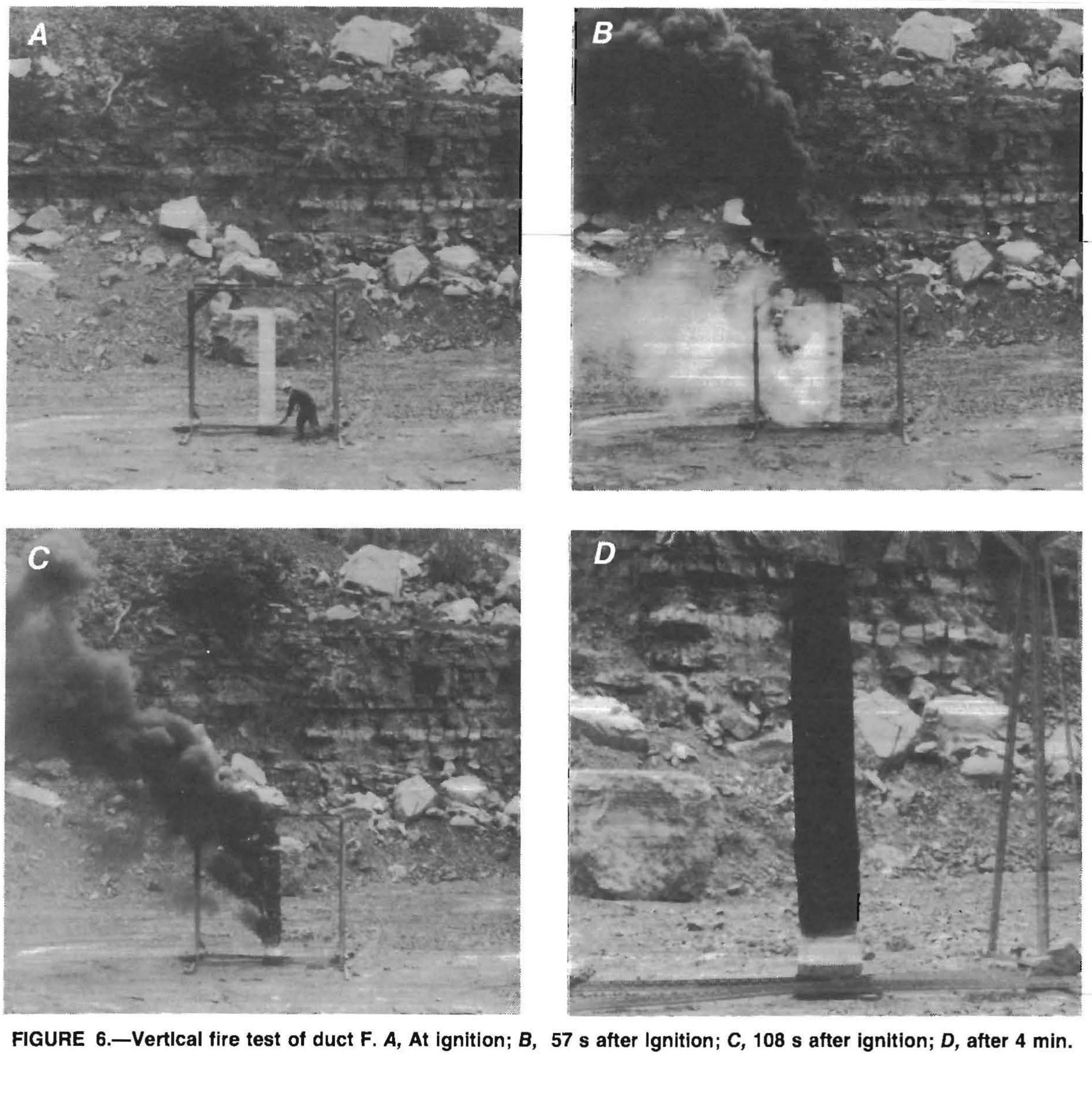


**FIGURE 6.—Vertical fire test of duct F.** ***A,*** **At ignition;** ***B,*** **57 s after ignition;** ***C,*** **108 s after ignition;** ***D,*** **after 4 min.**

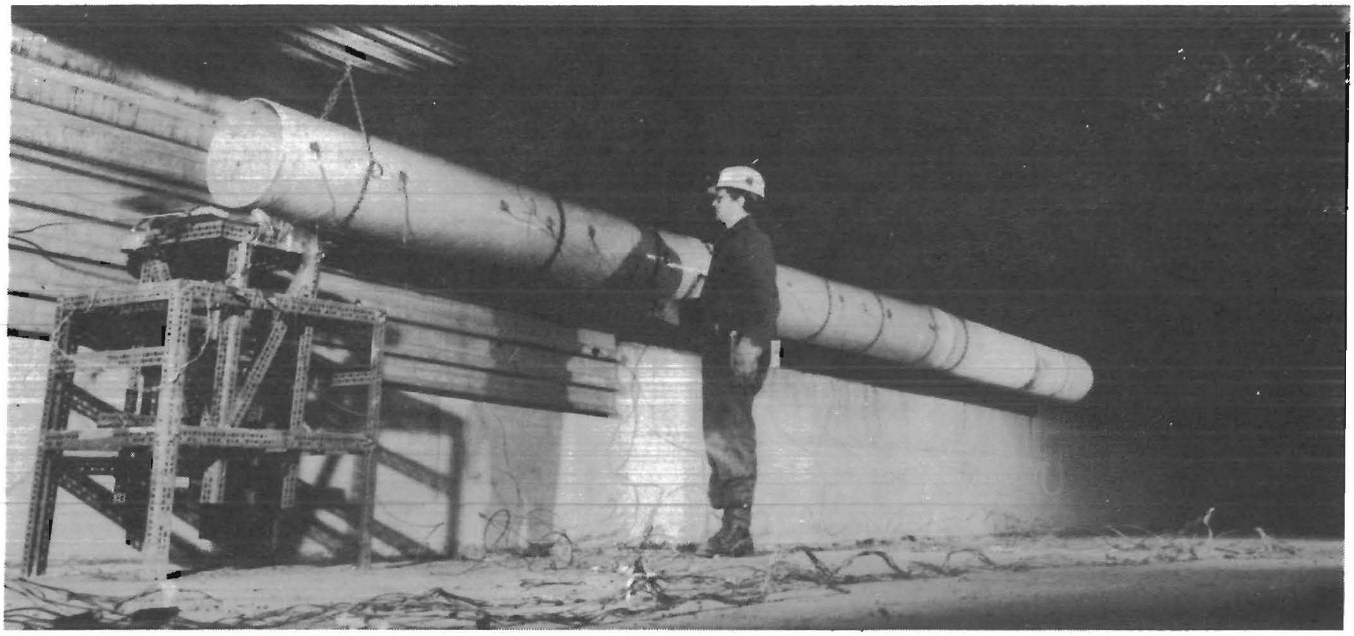

FIGURE 7.—Test arrangement for full-scale in-mine fire tests of ventilation ducts.

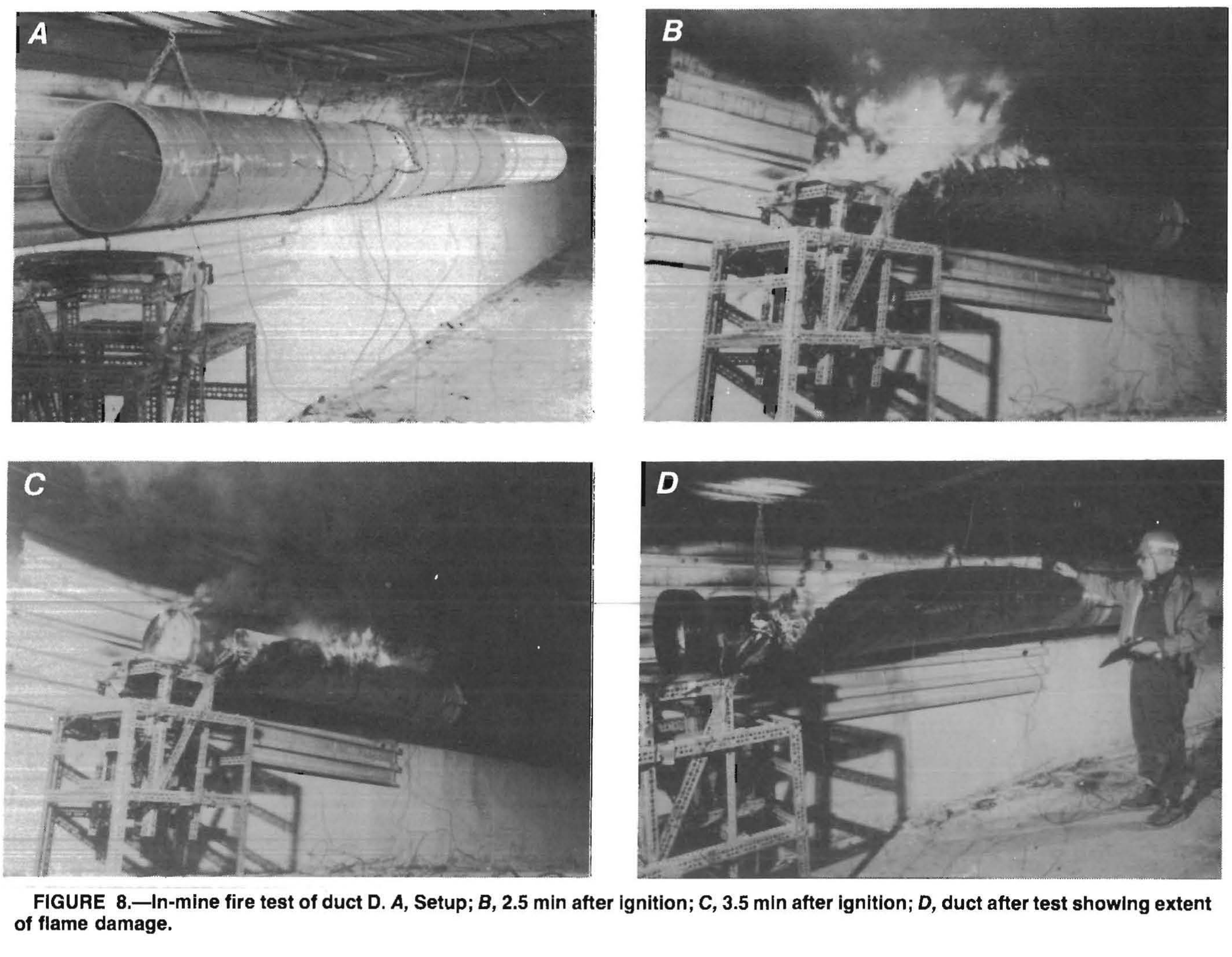


FIGURE 8.—In-mine fire test of duct D. *A*, Setup; *B*, 2.5 min after ignition; *C*, 3.5 min after ignition; *D*, duct after test showing extent of flame damage.

self-extinguished. Panel *D* shows the ducting after the test.

The four remaining 16-in-diam duct samples, B, C, E, and F, all failed the in-mine test due to the propagation of flames over the entire sample length. The flame spread rates ranged from 3.1 to 9.8 ft/min. During the tests, large quantities of smoke were produced and carried downstream by the ventilation flow. The remains consisted of a charred fiberglass carcass, as shown in figure 9 for duct F. Weight losses due to the burning of the combustibles in the duct ranged from 10 to 40 pct and were mainly dependent on the ratio of combustible to inert ingredients.

Figure 10 shows the temperature-time profiles obtained from every other thermocouple during the in-mine test of duct B. As the flame spread down the duct, the thermocouples at each position indicated steadily increasing temperatures, which maximized at about 800° C and then fell after the burning subsided. A temperature of 310° C is used to signify the flame-front arrival at a thermocouple position. The best-fit straight line intersecting each profile at about the 310° C point (solid line in figure 10) indicates the region of steady-state burning and is used to determine the flame-front position as a function of time and the flame spread rate. Deviation from this straight line, as indicated by the dashed line in figure 10, occurred during the ignition phase of the test.

Two in-mine fire tests were also conducted with 30-ft lengths of 12- and 20-in-diam ducts obtained from the same

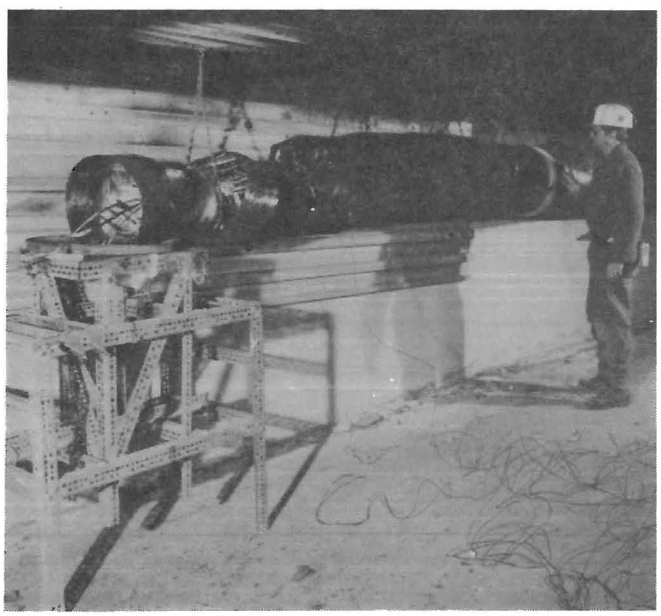

FIGURE 9.—Charred fiberglass carcass of duct F after in-mine fire test.

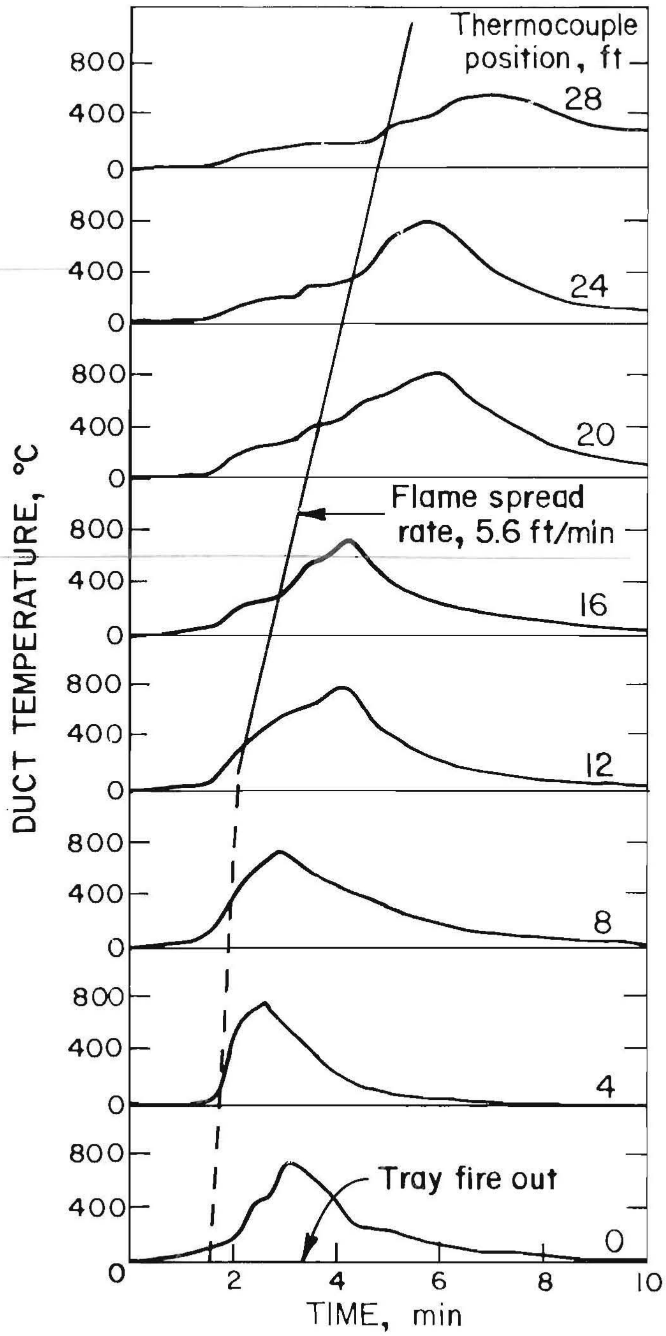


FIGURE 10.—Temperature-time profiles of duct B during in-mine fire test. Solid line indicates the flame position with time during steady burning; dotted line indicates the erratic flame position during ignition.

manufacturer as ducts C and D. The concentrations of fire retardant in these ducts were similar to that of duct D, a 16-in-diam duct, which passed the in-mine test. However, both the 12- and 20-in-diam ducts failed the test, with flame spread rates of 1.2 and 1.5 ft/min, respectively. These failures are attributed to slight sample variations from duct D, and not size, since the flame spread rates were nearly identical for the 12- and 20-in-diam ducts. Figure 11, panels *A* through *D*, illustrates the in-mine fire test of the 20-in-diam duct.

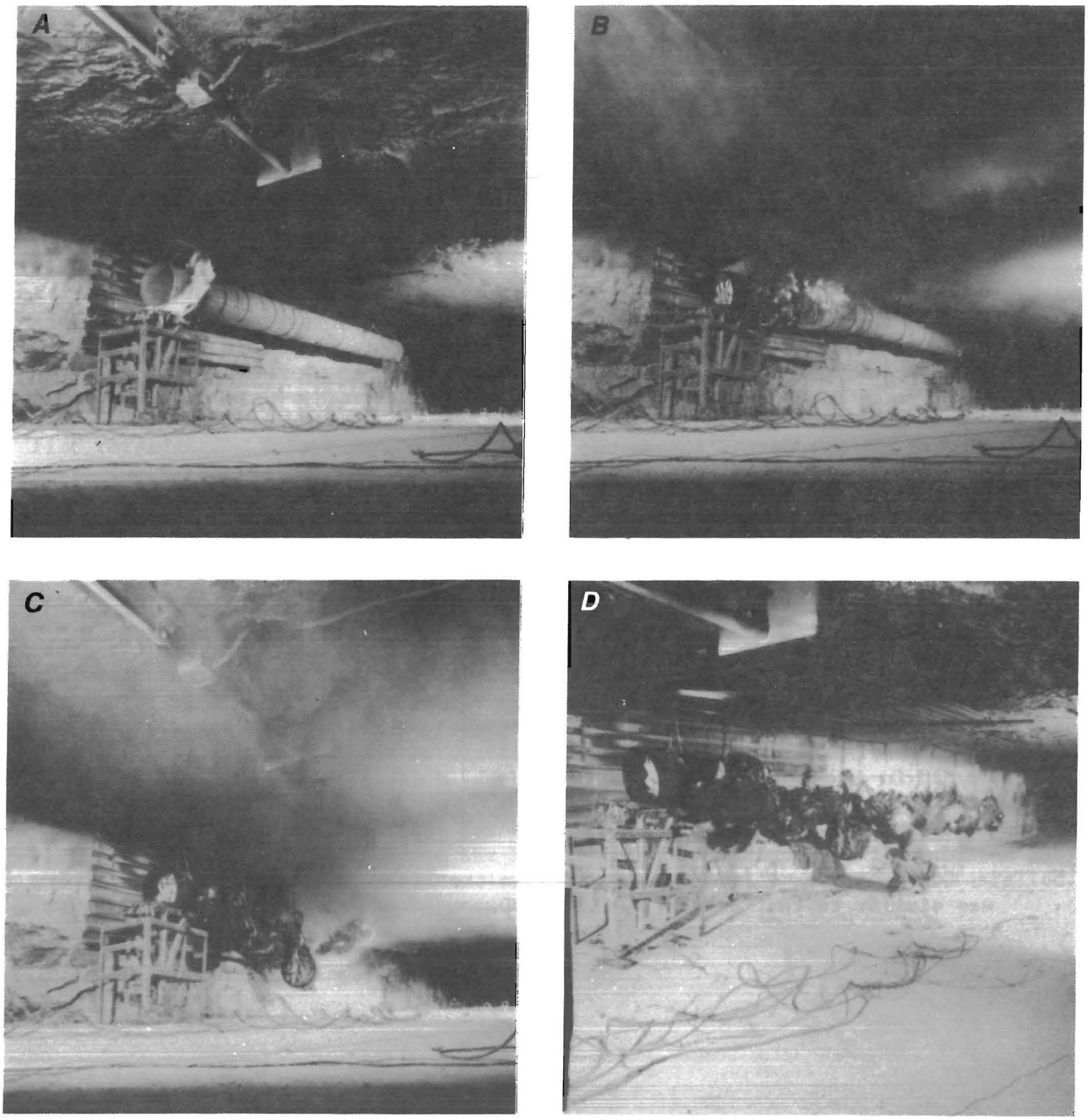


**FIGURE 11.—In-mine fire test of 20-in-diam ventilation duct. *A*, Ignition; *B* and *C*, flame propagation; *D*, charred fiberglass carcass.**

Panel *A* shows the start of the test. In panels *B* and *C*, the flame front is propagating down the ducting after the ignition source has burned out. Panel *D* shows the charred fiberglass remains after the test. Approximately 40 wt pct of the original 180 lb of ducting was burned in 16 min.

The flame position versus time for all the ducts that failed the in-mine test is shown in figure 12. The solid lines indicate steady-state flame spread and the slopes of the lines are the flame spread rates. The steeper slopes of most of the dashed lines are a result of the influence of the tray fire. Duct E took more time to reach steady-state burning than did the other samples. These apparant anomalies are expected since the processes that govern ignition and uniform flame propagation are different. Duct C had the fastest flame spread rate of 9.8 ft/min, two to three times greater than the other 16-in-diam duct samples. The flame spread rates of the 12- and 20-in-diam ducts are similar to each other and had the slowest flame spread rates measured in the in-mine tests.

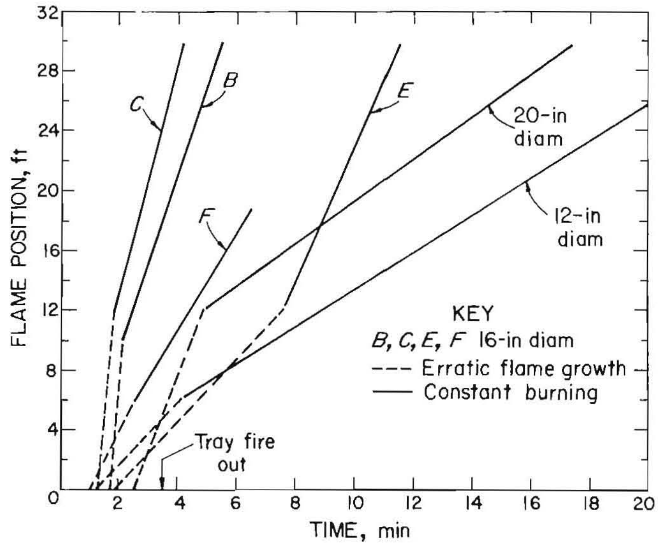


**FIGURE 12.—Flame position versus time for in-mine fire tests of ducts that failed.**

The results of all the in-mine tests are summarized in table 5. The table gives the number of feet of ducting that burned, the steady-state flame spread rate, and whether the duct passed or failed the test.

TABLE 5. - Results of full-scale in-mine fire test

| Duct | Length of duct, burned, ft | Flame spread rate, ft/min | Pass or fail |
|---|---|---|---|
| A...................... | 0 of 20 | 0 | Pass. |
| B...................... | 30 of 30 | 5.6 | Fail. |
| C...................... | 30 of 30 | 9.8 | Do. |
| D...................... | 8 of 20 | SE | Pass. |
| D1,12-in-diam[1].......... | 30 of 30 | 1.2 | Fail. |
| D2, 20-in-diam[1]......... | 30 of 30 | 1.5 | Do. |
| E...................... | 30 of 30 | 4.3 | Do. |
| F...................... | 20 of 20 | 3.1 | Do. |

SE Self-extinguished.

[1]Concentration of fire retardant in the 12- and 20-in-diam ducts was similar to that of the 16-in duct D.

## CONCLUSIONS AND RECOMMENDATIONS

Of the six 16-in-diam FRP ducts tested in this study, only duct A passed the large-scale vertical fire test, and only duct A and the 16-in-diam duct D passed the full-scale in-mine test. The rapid burning of most of the ducts in the vertical configuration and the sustained flame spread observed in the in-mine tests indicate the need for improved fire resistance, similar to that of duct A. This might be achieved by the addition of more fire retardant to the plastic resin. Because of an increase in the concentration of fire retardant in duct D compared with that in duct C, duct D passed the in-mine test. Although the for mulation for the 12- and 20-in-diam ducts was similar to that for 16-in-diam duct D, they failed the in-mine test. How-ever, the flame spread rates for these ducts were slow compared with those for the other ducts that failed. Duct A was heavier than the other 16-in-diam ducts and contained aluminum trihydrate as the major fire retardant. Unfortunately, the cost of a 10-ft section of duct A is about three times that of the other ducts.

The interpretation of the duct fire behavior in the large-vertical and in-mine tests would be difficult based on the laboratory-scale ASTM fire tests. Several of the ducts that had flame spread indices of 25 or less, failed the large-scale vertical and in-mine tests. The limiting oxygen index and flame spread index for duct F was similar to those for duct A, yet duct F failed the vertical and in-mine fire tests, which duct A passed.

The agreement of the results for the five FRP ducts tested by MSHA and the Bureau in the $S^3FT$ apparatus was excellent. There was also good agreement between the $S^3FT$ results and the performance of the ducts in the large-scale vertical and full-scale in-mine fire tests. The one exception is duct D, which passed the in-mine test, extinguishing after burning 8 ft, but failed the vertical fire test and $S^3FT$. The agreement between the $S^3FT$ and large-scale vertical test could be fortuitous considering the drastic differences in test procedures, such as a vertical versus horizontal duct configuration. Additional large-scale vertical fire tests of ducts that pass the $S^3Ft$ are required to verify this agreement. Nevertheless, the $S^3FT$ provides a good assessment of the flammability behavior of FRP ducting under realistic test conditions.

Since the completion of this study, several manufacturers have produced FRP ducts that passed all the MSHA voluntary standards for ducting (8). MSHA has issued these ducts a VT (Ventilation Tubing) number, which is stamped on the ducting. The VT ducts pass the $S^3FT$ and would probably pass the full-scale in-mine fire test, but might not pass the more severe large-scale vertical test. Due to the rapid burning observed in the vertical fire test, the use of most FRP ducts in vertical runs and steep slopes should be avoided. Since FRP ventilation ducting is used widely in the vertical and sloping configuration in metal and nonmetal mines, the extension of the voluntary acceptance procedures for underground coal mines (8), which includes the $S^3FT$, are recommended for the noncoal mines. In critical areas where FRP ducts are used in shafts, potential duct ignition sources should be eliminated and/or automatic supression systems installed.

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