Fire Doors for Noncoal Mines

By Kenneth L. Bickel and William H. Pomroy
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<th>Abbreviation</th>
<th>Description</th>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>°F</td>
<td>degree Fahrenheit</td>
<td>min</td>
<td>minute</td>
</tr>
<tr>
<td>ft</td>
<td>foot</td>
<td>pct</td>
<td>percent</td>
</tr>
<tr>
<td>ft/min</td>
<td>foot per minute</td>
<td>s</td>
<td>second</td>
</tr>
<tr>
<td>ft³/min</td>
<td>cubic foot per minute</td>
<td>st</td>
<td>short ton</td>
</tr>
<tr>
<td>h</td>
<td>hour</td>
<td>yr</td>
<td>year</td>
</tr>
<tr>
<td>in</td>
<td>inch</td>
<td></td>
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</tbody>
</table>
FIRE DOORS FOR NONCOAL MINES

By Kenneth L. Bickel and William H. Pomroy

ABSTRACT

During an underground mine fire, the importance of controlling the spread of smoke and toxic gases with suitable ventilation structures has been proven. However, under certain conditions, control of the propagation of the fire itself may be even more critical in insuring a safe mine evacuation. Fire doors offer the means for accomplishing both objectives. In 1978, the Bureau of Mines initiated research to evaluate the state of fire-door technology and develop and test a fire door suitable for large openings (10 by 12 ft or larger) in noncoal underground mines.

This report discusses current fire-door technology in the context of the underground mine environment and the design, fabrication, lab testing, and in-mine field testing of a mineworthy fire door. This door has a 1.5-h fire resistance rating and limits temperature rise across the door to 250°F during the first 30 min of fire exposure.

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INTRODUCTION

From 1965 to 1984, 177 noncoal underground mine fires were reported to Federal mine safety authorities, and about 90\% of the 121 fatalities resulting from these fires were caused by exposure to smoke and toxic gases.\(^3\) The control of smoke and gases during an underground mine fire is critically important. Under certain conditions, however, controlling the propagation of the fire itself may be even more critical in insuring a safe mine evacuation. Fire doors are a practical means for limiting the spread of toxic combustion products and controlling fire propagation. Because of the value of fire doors, recent Federal mine safety regulations include requirements for installing them in specified areas. Although these regulations permit alternatives to fire doors under certain circumstances (routing air directly to an exhaust system, mechanical ventilation reversal, effective evacuation, or installation of an automatic fire-suppression system), fire doors are often preferred due to factors such as mine layouts, operating practices, and ventilation plans. However, because no design guidelines or construction specifications for mineworthy fire doors for large underground openings were available, the fire-door option was not feasible for many mines.

In 1978, the Bureau of Mines initiated a research and development contract to evaluate the state of fire-door technology and develop and test a fire door suitable for large openings in noncoal underground mines. These research results were intended to guide subsequent development efforts by door manufacturers, eventually resulting in commercial products. Some mines may also wish to develop workable designs on their own. Shop drawings of each door are included in the appendix of this report.

Initial phases of the research are described in detail in a progress report submitted to the Bureau by the contractor, Unidynamics, Inc. (2). Results of these initial phases are also summarized in a previous Bureau report (3) and are briefly highlighted in this report. Because the contract was terminated prior to completion results of later phases of the contract, and subsequent efforts by Bureau personnel to complete the program, have not been previously reported.

ANALYSIS OF MINE DOORS CURRENTLY IN USE

The study was initiated by determining the types of doors currently in use in underground mines. The five categories included—

1. roll doors.
2. swing doors with panels opening in the same direction.
3. swing doors with panels opening in opposite directions.
4. telescoping doors.
5. sliding doors.

Most doors were operated either electrically or by compressed air. Of the five-door types encountered underground, only two (roll doors and sliding doors) were rated. Each door was held open by a fusible link that would melt during a fire, allowing gravity to close the door. Of the five door types studied, only three (roll doors, telescoping doors, and sliding doors with panels opening in opposite directions) were observed in current mine use in the desired size range (10 by 12 ft or larger), however, all door types are discussed in detail below.

DOOR DESCRIPTIONS AND OPERATING CHARACTERISTICS

Roll doors, sometimes referred to as roll-down doors, consist of a series of horizontal metal slats, which are interlocked to allow them to roll around a metal shaft when the door is opened.
(raised vertically), with little air leakage between the slats when the door is closed. The doors are electrically operated and controlled by pushbutton or lanyard.

Swing doors with panels opening in the same direction are generally designed so that two air cylinders, one connected to each panel, are operated in tandem to open the door. Swing doors with panels opening in opposite directions are generally designed so that the panels are connected by a linkage and operated by a single air cylinder. The doors are controlled by a lanyard located away from the door or by the use of photoelectric cells triggered by a passing vehicle.

The telescoping door consists of a series of horizontal, channel-shaped sheet metal sections that stack on each other. As the lowest section is lifted by two cables wound on a drum, it nests into the next section directly above it and lifts it also. This process continues until all sections have been lifted and the door is open. The door is electrically operated and controlled by pushbutton or lanyard.

The sliding door consists of a door panel fitted with rollers on top. The rollers ride in a horizontal track above and parallel to the plane of the door opening. The door is generally opened and closed manually. The door can be made self-closing by slightly inclining the track.

ASSESSMENT OF THE SUITABILITY OF EACH DOOR TYPE FOR USE AS A MINE FIRE DOOR

Each door type was analyzed with respect to the requirement for a mine-worthy, 1.5-h rated fire door for large mine openings. The advantages and disadvantages of each door type are given in table 1.

Although some rated roll doors had been observed in mine use, general-purpose application of this door type throughout the noncoal mining industry was judged impractical due to its susceptibility to blast, mobile equipment, and ground movement damage. Such damage could render the door inoperable. Smoke leakage or fire propagation could be experienced if the door were stuck in the "up" position during a fire, and passage of escaping miners would be inhibited if the door were stuck in the "down" position.

The primary deficiency of swing doors with panels opening in the same direction is the difficulty encountered in opening (or closing) the panels against a high ventilation pressure. Even in mines with relatively low pressure differentials, high pressures can be created by a fire. During a fire, airflows can be reversed, greatly altering the opening and closing characteristics of a door from normal conditions.

The disadvantages of swing doors with panels opening in opposite directions are minor. Although debris on the floor may hinder door operation, this is seldom a problem in the many mines that now use this type door for ventilation control. Likewise, although a floor trough is required to accommodate a bottom linkage for some designs, most do not, and since a concrete bulkhead and threshold are often installed in door openings anyway, the requirement for a floor trough would add little cost or complexity to an installation.

Like the slats of a roll door, the sections of a telescoping door are susceptible to damage from ground movement, blasting, and passing vehicles. Misalignment of the track or bent door sections could render the door inoperable. As with the roll door, smoke leakage or fire propagation could be experienced if the door became stuck in the "up" position, and escaping miners could be prohibited from passing if the door were stuck in the "down" position.

The principal disadvantage of the sliding door is that an area alongside the door opening, large enough to accommodate the door panel, is required. In large openings (20 to 30 ft is not unusual), an area of this size would be quite costly to excavate. Also, the difficulty in achieving an effective seal around the door edges, which is characteristic of sliding doors, is much more pronounced as the area of the door increases.

Based on the foregoing assessment and the information in table 1, the swing door with panels opening in opposite
**TABLE 1. - Advantages and disadvantages of each door type**

<table>
<thead>
<tr>
<th>Door Type</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roll doors</td>
<td>Raises and lowers vertically; not susceptible to damage from debris on roadway (however, debris may impair a bottom seal). Channels on either side of door. Complete door and operating mechanism mountable on bulkhead.</td>
<td>Space required above door to house operating mechanism and door. Constructed of sheet metal; susceptible to damage from ground movement, equipment, and blasting. Slight misalignment of channels and/or slats may render door inoperable. Maintenance and lubrication required so corrosion does not render door inoperable. In large openings or high differential pressures, the door may deflect excessively, rendering it inoperable.</td>
</tr>
<tr>
<td>Swing doors with panels opening in same direction.</td>
<td>Very rugged. Adjustable opening and closing speed.</td>
<td>A high-pressure differential across the door could make opening and/or closing door difficult or impossible and sealing around door perimeter difficult. Debris on the floor may prevent door from closing. Two air cylinders are generally required to operate door. Where possible to mount an air cylinder on mine roof, one air cylinder can be used with a rod connected to top of each panel. Debris on floor may prevent door panels from closing properly. Some designs required a floor trough to accommodate a bar linkage at bottom of door.</td>
</tr>
<tr>
<td>Swing doors with panels opening in opposite directions.</td>
<td>Air pressure differential across door opening has little effect on power required to open and close doors and makes sealing around edges simpler. Very rugged. Doors can be set at desired opening and closing speed.</td>
<td>Susceptible to damage from equipment, blasting, and ground movement. Space required above door to store raised door sections and house operating mechanism. Contains many separate pieces, all of which must fall into place by gravity for door to operate.</td>
</tr>
<tr>
<td>Telescoping doors.</td>
<td>Raises and lowers vertically; not susceptible to damage from debris on roadway (however, debris on floor may prevent bottom seal). Channels on either side of door provide good air seal.</td>
<td>An area alongside each opening large enough to accommodate door is required. Difficult to achieve effective seal around door edges.</td>
</tr>
<tr>
<td>Sliding doors.</td>
<td>The door panel or panels can be setup on an inclined track to provide self-closing. Air pressure has little effect on the opening or closing force required.</td>
<td></td>
</tr>
</tbody>
</table>
directions was determined to be best suited for use as an underground mine fire door. However, since no such door had ever been tested or rated for the desired 1.5-h fire resistance, appropriate door design criteria and construction specifications were unknown. It was therefore determined that a design for such a door should be developed and that the design should be verified by subjecting a prototype door to a 1.5-h fire resistance test.

IMPROVED FIRE-DOOR DESIGN AND TESTING

Design criteria for the improved fire door were established as:

1. Type: The swing door with panels opening in opposite directions was selected because the design allows air pressure to be balanced on the panels, and because it can be ruggedly built.

2. Size: The maximum size door that will fit into the fire-door test fixture at Underwriter's Laboratories (UL) is 12 by 10 ft. (Larger door sizes may be approved by UL based on fire testing of doors up to 12 by 10 ft followed by additional analysis.)

3. Long-life: The door was designed to last for over 200,000 cycles, or for at least 5 yr.

4. Fire rating: A fire-door rating of 1.5 h was specified.

5. Means of operation: Compressed air.

6. Design pressure differential: 6-in-w.g. pressure differential across the door with higher pressure ratings possible.

FIRST-GENERATION FIRE DOOR

The first-generation fire door consisted of 11-gauge sheet steel welded to a steel frame, with steel strip horizontally welded to the face of the door for reinforcement. Neoprene door seals were used for sealing around the perimeter of the door. The door assembly included a 2-ft 6-in by 6-ft 8-in airlock, one-person man door.

Mockup testing was conducted in the laboratory, using a specially constructed test fixture. The test fixture consisted of a 12- by 16-ft plywood box (with the door assembly comprising one side), a fan for blowing air inside the box, and an airbag attached to the outside of the door side of the box for determining leakage through the door assembly. Figures 1 and 2 show, respectively, the fire-door air-pressure test fixture with door assembly, man door, and fan installed; air-pressure test-fixture with airbag installed.

A manometer was used to measure air pressure differential across the door. With the fan blowing, a sliding regulator panel in the plywood box was adjusted until the desired 6-in-w.g. steady-state pressure differential across the door was achieved.

Air leakage through the door assembly was determined by measuring air velocity through a 2.5- by 6.7-ft opening in the airbag. Five measurements were made, yielding an average velocity of 270 ft/min. Total leakage through the fire door-man door assembly was thus 4,523 ft³/min, well within the design goal of 8,000 ft³/min at 6-in-w.g. pressure differential.

After leakage tests, the airbag was removed and door deflection measurements taken. With the doors closed, three lengths of mechanic's wire were stretched horizontally across the downstream side of the door assembly; one at the top of the doors, one at the center, and one at the bottom. The distance from the wire to the door was measured at three points along each wire (hinge line, center, and edge) for each door panel (right and left). After these initial conditions were recorded, the fan was started and the regulator panel adjusted to achieve the desired 6-in-w.g. pressure differential across the door assembly. At this pressure differential, the distances between the wires and door panels were remeasured and the door deflections calculated. The door deflection test results are summarized in table 2. Under
FIGURE 1.—Fire-door air-pressure test fixture showing door assembly and fan.

FIGURE 2.—Fire-door air-pressure test fixture showing airbag.
TABLE 2. —Door deflection under conditions of pressure differential of 6-in w.g., first-generation door

<table>
<thead>
<tr>
<th>Location of measurement</th>
<th>Door deflection, in</th>
<th>Fan on</th>
<th>Deflection</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEFT PANEL</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Top:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hinge</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Center</td>
<td>6-1/8</td>
<td>5-11/16</td>
<td>7/16</td>
</tr>
<tr>
<td>Edge</td>
<td>4-1/8</td>
<td>3-5/16</td>
<td>13/16</td>
</tr>
<tr>
<td>Center:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hinge</td>
<td>1-1/2</td>
<td>1-1/2</td>
<td>0</td>
</tr>
<tr>
<td>Center</td>
<td>6-3/8</td>
<td>5-1/2</td>
<td>7/8</td>
</tr>
<tr>
<td>Edge</td>
<td>4-5/16</td>
<td>2-13/16</td>
<td>1-1/2</td>
</tr>
<tr>
<td>Bottom:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hinge</td>
<td>1-1/2</td>
<td>1-1/2</td>
<td>0</td>
</tr>
<tr>
<td>Center</td>
<td>6-3/16</td>
<td>5-5/16</td>
<td>7/8</td>
</tr>
<tr>
<td>Edge</td>
<td>4-3/8</td>
<td>2-11/16</td>
<td>1-1/2</td>
</tr>
<tr>
<td>RIGHT PANEL</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Top:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hinge</td>
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<td>0</td>
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<tr>
<td>Center</td>
<td>5-15/16</td>
<td>5-1/2</td>
<td>7/16</td>
</tr>
<tr>
<td>Edge</td>
<td>3-1/2</td>
<td>2-11/16</td>
<td>13/16</td>
</tr>
<tr>
<td>Center:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hinge</td>
<td>1-1/2</td>
<td>1-7/16</td>
<td>1/16</td>
</tr>
<tr>
<td>Center</td>
<td>2-5/16</td>
<td>1-5/8</td>
<td>11/16</td>
</tr>
<tr>
<td>Edge</td>
<td>3-1/2</td>
<td>2-1/16</td>
<td>1-7/16</td>
</tr>
<tr>
<td>Bottom:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hinge</td>
<td>1-1/2</td>
<td>2-1/2</td>
<td>0</td>
</tr>
<tr>
<td>Center</td>
<td>6-1/8</td>
<td>5-5/16</td>
<td>13/16</td>
</tr>
<tr>
<td>Edge</td>
<td>3-7/8</td>
<td>2-1/8</td>
<td>1-3/4</td>
</tr>
</tbody>
</table>

These test conditions, equivalent to a load of 1.87 st distributed over the door's surface, the maximum deflection measured was 1-3/4 in. It was also demonstrated that one person, by pushing on one door panel, could easily open the door despite the 6-in-w.g. pressure differential. A cycling test was performed to identify weaknesses in the mechanical design of the hinge assembly and opening-closing mechanism. After opening and closing the door every 15 s for approximately 1 h, no change in door operating characteristics was observed.

After successful mockup testing, the door was sent to UL for a 1.5-h fire rating test. The door (without adjoining man door) was built into a 16-in masonry wall contained within a test frame (fig. 3) and sealed using the neoprene seals.
After the masonry wall had seasoned, the fire test was conducted in accordance with UL standard 108 (4). The test frame was attached to a test fixture containing gas ports (to provide fuel for the fire) and thermocouples (to measure temperatures on the fire side of the door) (fig. 4). Temperatures within the furnace were in accordance with the standard time-temperature curve for fire-door testing (fig. 5). Throughout the fire test, observations were made to note the character of the fire and its control, the condition of the exposed and unexposed faces, and all developments pertinent to the doors as a fire barrier, with special reference to stability and flame passage (fig. 6).
FIGURE 4.—Fire-door fire-test fixture showing gas ports and thermocouples.
The fire was luminous and well distributed during the fire test. Deflection of the doors was determined by measurements at about the center point of a horizontal wireline stretched across the midheight of the doors. During the first few minutes of fire exposure, the doors began to bow away from the fire. The deflection at the center of the doors reached a maximum of 3-1/4 in at 60 min. At 4 min, the faces of both doors began to buckle slightly. Flaming occurred along the neoprene seal at the meeting edge of the doors after 11 min, 20 s. The seal fell off the door after 30 s and continued to flame violently on the floor until extinguished. After 15 min of fire exposure, the doors had deflected 1-1/2 in at the top, along the meeting edge, and in a direction perpendicular to the face of the doors. The doors continued to deflect and reached a maximum of 3 in after 60 min of fire exposure. After 25 min, 50 s, flaming occurred along the seal at the top of the doors. After 26 min, flaming occurred at the top of the hinge tube on the North door. After 28 min, flaming also occurred along the entire hinge edge, and between the door and the fire-door frame at a point 52 in up from the bottom of the door. At 44 min, flaming occurred along the bottom of the doors on the neoprene seal. The fire test was halted after 60 min.
FIGURE 6.—Technician measuring door deflections during fire test.
At the conclusion of the fire test, it was determined that the door failed the 1.5-h fire rating test because of the following:

1. A 3-in deflection occurred along the upper meeting edge of the two panels. This deflection exceeded the thickness of the doors and allowed the passage of flame through the door (fig. 7).

2. An opening occurred between the door and frame along the hinge edges because the neoprene seal burned away.

SECOND-GENERATION FIRE DOOR

The second-generation fire-door design was similar to the first door, however, changes were made to structurally reinforce the door panels and to improve the door seal using material with a higher fire-resistance rating. The second door consisted of 14-gauge sheet steel over a steel frame, with 5-in-wide steel channel welded to the skin both horizontally and diagonally for reinforcement. It was determined that the thinner 14-gauge steel would tend less toward warping the door's frame. A material specifically designed for fire doors was used for sealing around the edges of the panels.

After successful mockup testing, using the same test fixture and procedures used for the original door, the second door was sent to UL for fire testing (fig. 8). The fire test procedures were identical to those employed during fire tests of the original door. The door was built into a 16-in-thick masonry wall contained within the steel test frame. After the wall had seasoned, the test was conducted in accordance with UL Standard 10B "Fire Tests of Door Assemblies". The fire was luminous and well distributed during the entire test. The furnace temperature was controlled in accordance with the standard time-temperature curve for fire-door testing (fig. 5). At no time during the test did any of the door-panel seals show any signs of combustion or deterioration. The door panels did bow and buckle slightly, and a deflection along the meeting edge of the door panels was observed; however, at no time did the deflection exceed the thickness of the door, nor was flame passage through the door observed. As a result, this door successfully passed the UL Standard 10B 1.5-h fire rating test (fig. 9).

THIRD-GENERATION FIRE DOOR

After testing the second-generation fire door, the following mandatory regulations were promulgated by the Mine Safety and Health Administration (MSHA) for metal and nonmetal underground mines (5):

30 CFR 57.4-61A:

To prevent the spread of smoke or gas in the event of a fire, ventilation doors shall be installed at or near shaft stations of intake shafts and at any shaft designated as an escapeway under standard 57.11-53 or at other locations which provide equivalent protection. Doors constructed by this standard shall be constructed according to the specifications within the definition of "fire door" in section 57.2, if located in a timbered area, in an area where the exposed rock is combustible, or in an area where a significant fire hazard is present.

30 CFR 57.4-61B:

To confine or prevent the spread of toxic gases from a fire originating in an underground shop, the mine operator shall install in each opening to the shop a fire door or bulkhead constructed in accordance with the definition of "fire door" contained in section 57.2.

The definition of fire door contained in section 57.2 stated: fire door means an openable closure for a passageway, shaft, or other mine opening to serve as barrier to fire, the effects of fire, and air leakage. A fire door shall be constructed of materials and assembled so as to be equivalent to a door having a fire-resistance rating of
FIGURE 7.—Door deflection caused by exposure to test fire.
FIGURE 8.—Second-generation fire door undergoing fire test.

FIGURE 9.—Second-generation fire door after removal from the fire-test fixture.
1.5 h or greater, and on exposure to fire on one one side for 30 min, the temperature on the unexposed side shall not exceed 250°F, as determined by a nationally recognized testing agency in accordance with "Standard Method of Fire Tests of Door Assemblies," National Fire Protection Association (NFPA) Code 252, 1972, or equivalent. The framework assembly of a fire door and the surrounding bulkhead, if any, shall be at least equivalent to the fire door in fire and air-leakage resistance, and in physical strength. NFPA Code 252 is hereby incorporated by reference and made a part thereof.

This definition of MSHA's performance requirements for a fire door differed from the requirements contained in the preproposal draft of the standard in that the surface temperature-rise requirement was added. Thus, the second-generation fire door failed to satisfy MSHA's performance requirements as promulgated, because no provision had been made to limit the temperature rise on the surface of the downfire side of the door. In view of this deficiency, a third-generation fire door was designed to meet all requirements of the new definition.

A more recent regulation, 57.4760/61, effective April 15, 1985 (6), permits 1.5-h fire doors that do not satisfy the 250°F surface temperature requirements for areas of a mine that are more than 20 ft but less than 50 ft from timbered areas, combustible ore, or other combustible materials. This regulation further states that doors greater than 50 ft from such combustibles need meet only the requirements for a ventilation door.

The third-generation fire-door consisted of two 14-gauge sheet steel skins welded to either side of a steel frame, reinforced with 5-in-wide steel channel. The interior volume of the door (between the sheet steel skins) was filled with a 5-in-thick, asbestos-free mineral fiber insulation blanket (fig. 10). The door was subjected to the same deflection, cycling, and leakage tests as the first- and second-generation doors (fig. 11), with similar results. The door was then sent to UL for fire testing.

The door was also subjected to the same 1.5-h fire test as were the previous doors, however, surface temperatures were measured on the downfire side of the door in accordance with applicable provisions of "Standard for Fire Tests of Door Assemblies," UL Standard 10B.

The fire was luminous and well distributed during the fire test. After 3 min of fire exposure, the door faces began to buckle towards the fire between the supporting channels.

The deflections of each panel were measured using wires stretched across the opening. During the first few minutes of fire exposure, the doors began to bow towards the fire. The center deflection of the right and left panels reached a maximum 3-1/4 in and 3-5/8 in, respectively, at 75 min.

At 8 min, the top of the right panel at the meeting edge began to bow away from the fire. After 10 min of fire exposure, the door had deflected a maximum of 1-1/2 in at the top and along the meeting edge in a direction perpendicular to the face of the doors. After 19 min of exposure, the gasketing at the meeting edge of the doors began to smoke. At 33 min, the bottom sill channel began to bow in towards the fire. A maximum deflection of 1-1/2 in toward the fire was observed at 70 min. At 47 min, intermittent light flaming was observed at the top of the meeting edge of the doors. This flaming did not exceed a 6-in length or 1-min
duration. After 60 min, the smoke from the gasketing material was subsiding. At 62 min, flaming was observed at the upper hinge location of the north door; however, the flaming was contained within the door and did not extend past the plane of the door face to the unexposed surface. This flaming continued until 68 min.

During the 90-min fire-test duration no flaming was observed on the unexposed surface of the door assembly, nor through openings developed in the door assembly, and the latch remained engaged.

Ten thermocouples were arrayed over the downfire side of the door (fig. 12) to measure surface temperatures on the unexposed side of the door.
FIGURE 11.—Third-generation fire-door mockup testing.
FIGURE 12.—Thermocouples arrayed on downfire side of fire door during fire testing.
The unexposed surface temperature was 82°F prior to the test, and after 30 min of fire exposure, the average unexposed surface temperature rose to 158°F. The unexposed door-panel surface temperature over the entire 90-min test is shown in figure 13.

The appearance of the exposed face of the test assembly after the fire test is shown in figure 14 (note the sagging overhead linkage).

Based on observations of the door during the fire test and a thorough examination of the door following the fire test, UL issued a report stating the door, "demonstrated suitable protection for openings in walls requiring 1.5-h, 250°F maximum rise Fire Rated Door Assemblies."

IN-MINE TEST

Another third-generation door was installed at the Ozark Lead Company's Millikan mine near Sweetwater, MO, for long-term endurance testing (fig. 15). The 16 by 11 ft door was installed in a 20 by 14 ft main haulage drift near a shaft station. It functioned properly for approximately 6 months before being struck by a passing load-haul-dump vehicle. The door frame was damaged, causing excessive air leakage to occur. The door was repaired by mine personnel, except for the bottom seal on one panel. Approximately 15 months after the door was installed, it was evaluated for leakage and overall performance. At the time, pressure differential across the door was

![Graph showing temperature changes over time](image-url)

**FIGURE 13.**—Average surface temperatures of unexposed door panels during fire test of third-generation mine fire door.
less than 0.2-in w.g. Actual leakage could not be measured, as proper instruments for low velocity airflow measurement were not available at the minesite. However, a close visual inspection of the door revealed no apparent leakage points (with the exception of the missing bottom seal). The door was opened and closed numerous times to check for signs of undue wear or impaired operation. No degradation in door operation occurred during the endurance test period.
During an underground mine fire, controlling the spread of toxic gas and smoke is essential. If a fire were to occur in an area such as a shaft station or shop, however, controlling the spread of the fire itself may be even more important.

The Bureau analyzed the state-of-the-art of fire-door technology to determine the suitability of existing designs for underground mine use. As existing designs were found deficient, a new door, suitable for use in underground mines, was designed, fabricated, and subjected
to a 1.5-h fire rating test. This door failed the fire rating test due to excessive deflection of the door panels and the burning of neoprene edge seals. Therefore, a second-generation door was designed with greater structural integrity and fitted with seals having a higher fire resistance. This door successfully passed the UL Standard 10B fire test for 1.5-h rated fire doors.

A third-generation fire door was designed in response to an MSHA regulation, which required that fire doors be constructed and assembled so as to be equivalent to a door having a fire resistance rating of 1.5 h or greater, and, on exposure to fire on one side, the temperature on the unexposed side shall not exceed 250°F. The third-generation door was similar in construction to the second-generation door except a 5-in-thick blanket of thermal insulation was incorporated into each door panel to limit temperature rise on the downfire side. When fire tested, this door satisfied both the fire-resistance and temperature-rise test criteria. Another third-generation door was fabricated and installed in an operating underground mine for endurance testing. No design flaws or operating deficiencies were apparent after 15 months of mine use.

The three doors developed during this research program represent progressively increasing levels of fire protection for underground mines. The first-generation door, though not suitable as a fire door, is an excellent ventilation door, providing protection from the spread of smoke and toxic fire gases. Such doors are permitted under current MSHA regulations in areas greater than 50 ft from mine combustibles. The second-generation door also acts as a ventilation barrier and offers 1.5-h fire resistance as well. This door meets MSHA requirements for a fire door that is located more than 20 ft but less than 50 ft from timbered areas, combustible rock, or other combustible material. Finally, the third-generation door fulfills all requirements mandated by MSHA for fire doors, including 1.5-h fire resistance and limiting surface temperatures to 250°F for 30 min on the unexposed side. Where ventilation or fire doors are required, use of these, or equivalent doors, is recommended. Shop drawings of each door are included in the appendix to this report.

REFERENCES

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