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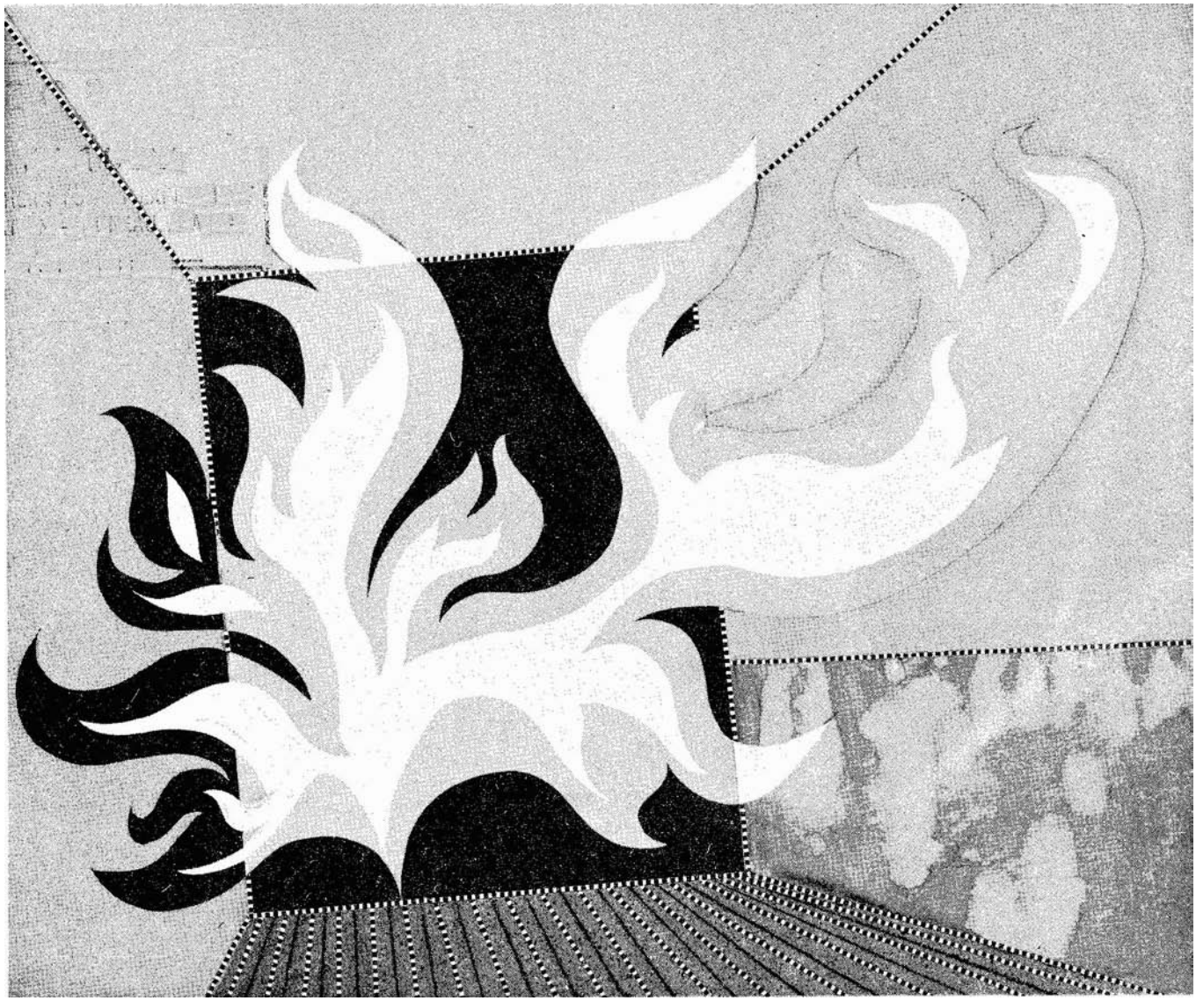
Effect of Wall Linings On Fire Performance Within a Partially Ventilated Corridor



SUMMARY

Research was conducted to determine the effect of three types of wall linings on fire performance within a partially ventilated corridor. Separate fire exposure studies were made with (1) essentially noncombustible corridor wall and ceiling surfaces, except for wood doors and trim, and a wood wainscot 3-1/2 feet high: (2) wood-grained, prefinished hardboard applied to both wall surfaces; and (3) Select grade, red oak flooring applied to both walls of the corridor. Under the test conditions, the burning of the wood fire cribs could exhaust the supply of air in the immediate vicinity of the cribs within 6 or 7 minutes, resulting in a flashover along the entire length of the corridor ceiling, as the hot, unburned combustible gases progressively reached an unused supply of oxygen. This flashover occurred at approximately the same time whether the wall linings were of combustible or noncombustible material and occurred before any appreciable flame spread along the wall lining.

Acknowledgments

Appreciation is extended to Mayor H. T. Owens of Waukesha, Wis., for arranging availability of the school building for this research; to William Clark, Fire Training Section, Wisconsin State Board of Vocational and Adult Education, and to Emery Downie, Waukesha Fire Chief, for providing the necessary fire protection during the tests; also to J. E. Bajorek, of the Masonite Corporation, for coordinating the program between the Laboratory and the American Hardboard Association.

Effect of Wall Linings On Fire Performance Within a Partially Ventilated Corridor[1]

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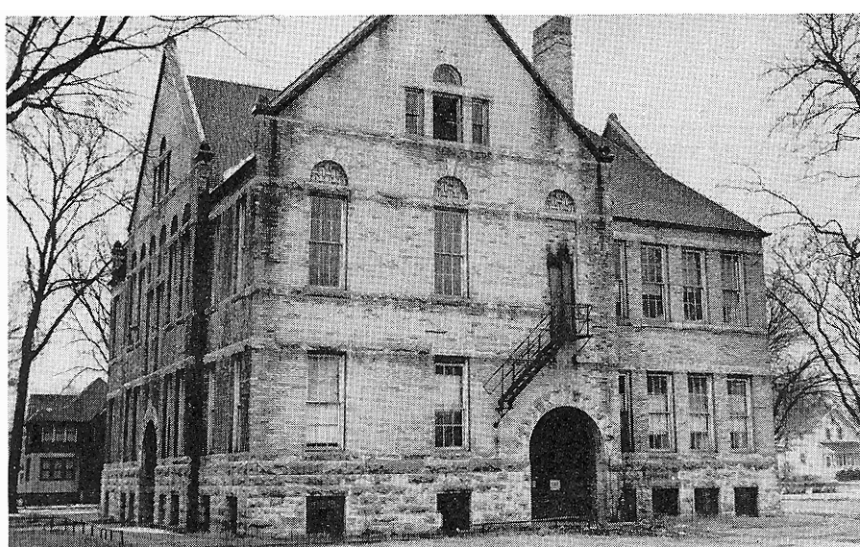
INTRODUCTION

Late in September 1964, the U.S. Forest Products Laboratory was informed that the State School for Boys at Waukesha, Wis., was being abandoned. The City of Waukesha, which had purchased the land from the state, indicated that it would cooperate with any organization interested in conducting fire research studies within the buildings before they were demolished. A cooperative research program was developed jointly by the Forest Products Laboratory and the American Hardboard Association to study the effects of various wall linings on fire performance in a partially ventilated corridor. The second story corridor of a two-story school building was selected as the test area. The building (fig. 1) was 80 to 90 years old and of wood frame construction with brick masonry exterior walls and plaster finished interior walls.

This Research Paper summarizes the research conducted and the results obtained.



(M 128 484)

Figure I.--General view of school building at former Wisconsin State School for Boys, Waukesha. Corridor used for tests is just beyond door at top of fire escape.

[1] In cooperation with the American Hardboard Association.

[2] Maintained at Madison, Wis., In cooperation with the University of Wisconsin.

CORRIDOR DESCRIPTION

The corridor selected for the fire performance tests was 11 feet wide, 72 feet long, and 13 feet high. A detail drawing of the corridor is presented in figure 2. The walls were approximately 16 inches thick and of brick masonry construction. Three doors and one entryway adjoined the corridor. One of the doors, an outdoor fire exit, was located at one end of the corridor (fig. 3). Two double-hung windows, each 40 by 102 inches, were located at the opposite end (fig. 4).

The interior walls and ceiling were finished with wood lath and plaster of sound and smooth construction. The ceiling lath was nailed to 2- by 12-inch wood beams and wall lath was nailed to 2- by 2-inch furring strips secured to the masonry walls. A white pine wainscot, 3-1/2 feet high, covered the full perimeter of the interior walls (figs. 3 and 4). Two slate blackboards were located above the wainscot for a distance of 20 feet from the window end of the corridor. The wainscot, doors, and trim were finished withvarnish. Apparently no finish remained on the hardwood floor. It was estimated that about 20 percent of the total wall and ceiling area of the original corridor had a combustible finish.

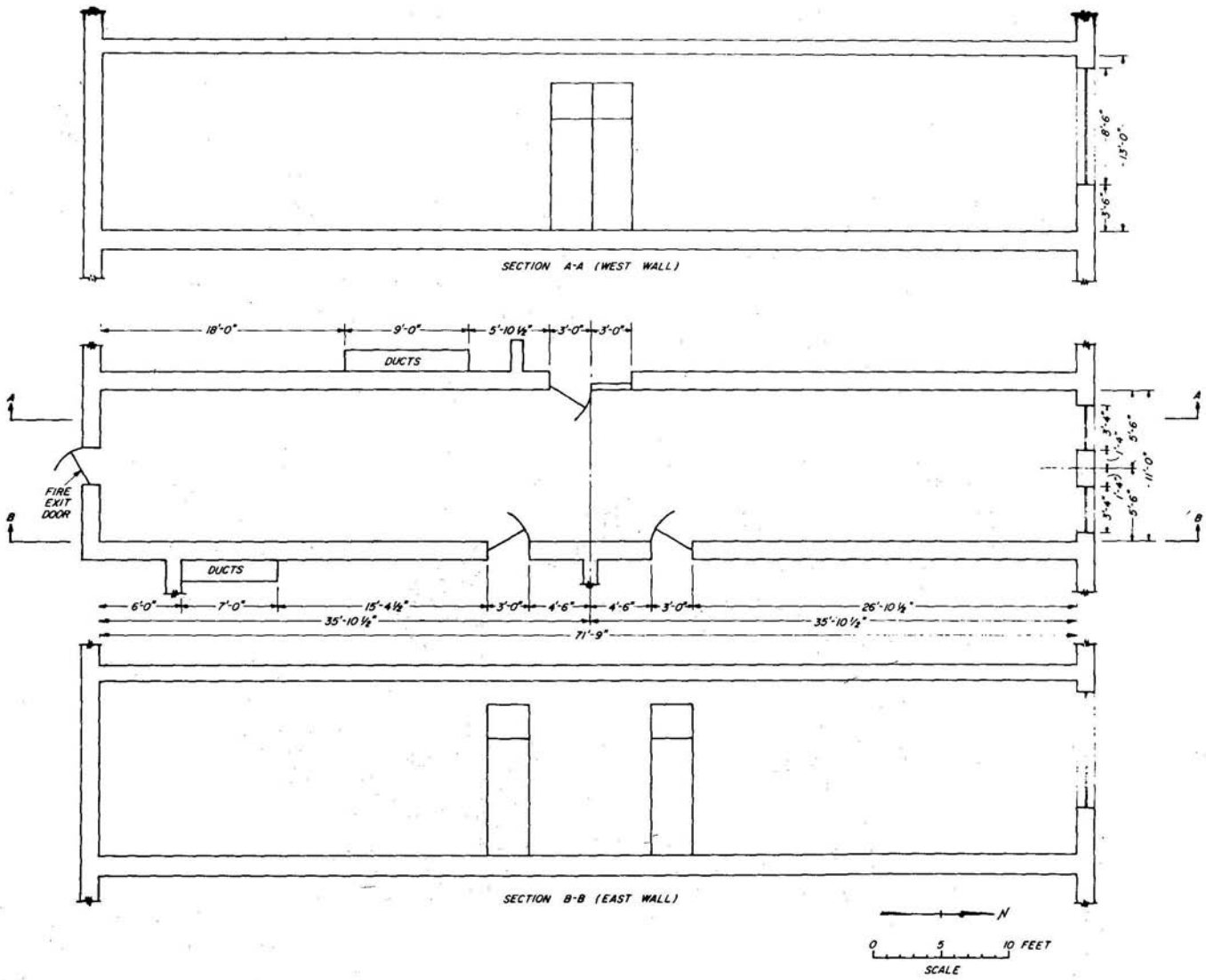


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Figure 2.--Drawing of corridor showing location of doors and windows and critical dimensions.

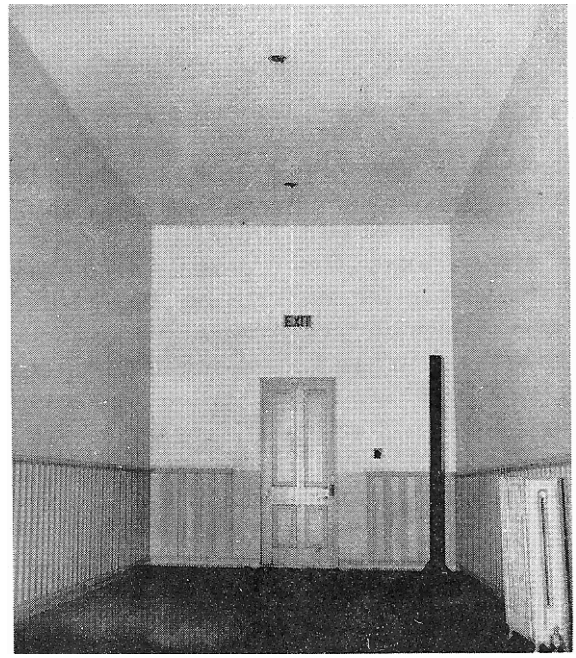

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Figure 3.--View of one-half of the corridor as it was originally near the fire exit end.

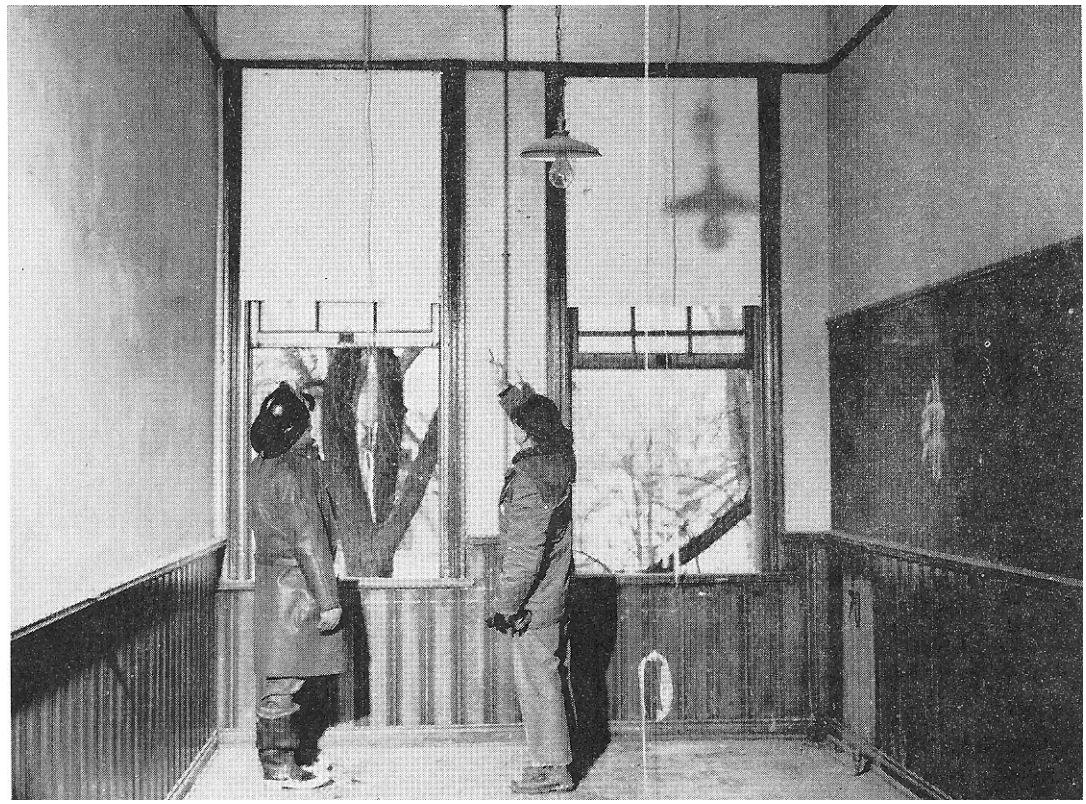

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Figure 4.--Windows at the one end of the corridor, which were opened halfway and the upper half blocked with asbestos millboard during the tests.

MODIFICATIONS OF TESTS

A series of three fire tests were conducted within this corridor. For the first test, the corridor was essentially in its original condition, with noncombustible walls and ceiling, except for doors, frames, and wood wainscoting; for the second test, the walls were covered with 1/4-inch thick, wood grained and prefinished hardboard; and for the third test, the walls were covered with red oak lumber (Select, flooring grade). Detail modifications for each test were as follows:

Initial Test (Test No. 1)

A half partition near one end of the corridor was removed to make the full 72-foot length available. The 6- by 8-foot entryway through the west wall was covered with gypsum board and a door installed for access to the corridor. The upper halves of the end windows were covered with asbestos sheeting, leaving openings approximately 40 by 50 inches (fig. 4). All transom windows above the doors were covered with gypsum board. Eight 1-foot-square test panels of hardboard, red oak, and fiberboard were placed on the east wall for the purpose of obtaining their relative ignition characteristics (fig. 5).

Hardboard Test (Test No. 2)

In addition to the modifications made in the initial test, the wainscot was removed from that portion of the walls to be clad with hardboard. Wood grained and random grooved, 1/4-inch-hardboard wall paneling of light and dark color,

(M 128 486)

Figure 5.--Installation of test panels to obtain relative ignition characteristics.

prefinished with a typical 1- to 3-mil coating of catalyzed synthetic resin, was nailed directly to the plaster and lath surface. This nailing was made with 4d casing nails at 4-inch centers for the panel edges and 6 inches on centers (16 inches inward from the edges) for vertical nailing. This hardboard was installed as 4- by 8-foot and 4- by 4-foot sheets, with the longer sheets placed above the smaller sheets (fig. 6). In areas where the plaster had been weakened or had fallen away from the wood lath, gypsum board was first nailed in place and then used as a backing for the hardboard. The light-colored hardboard was placed on the east wall, and the dark-colored hardboard on the west wall, both for a length of 48 feet from the ignition end of the corridor.

Two 42- by 48-inch asbestos sheets were placed on the ceiling directly above the ignition cribs to protect this area of the ceiling from fire damage during the test. Asbestos sheets and gypsum boards were also nailed in place on the ceiling wherever necessary to replace plaster that had fallen during the first test.

Red Oak Test (Test No. 3)

Select grade, red oak flooring, 25/32 inch thick, was nailed horizontally the entire height of the walls for a distance of 48 feet from the ignition end of the corridor (fig. 7). Nailing was done with 8d casing nails directly to wood-furring strips which originally supported the wood lath and plaster over the brick masonry walls. For this third test it was also necessary to nail gypsum wallboard panels on the ceiling to replace additional plaster which had fallen during the second test.

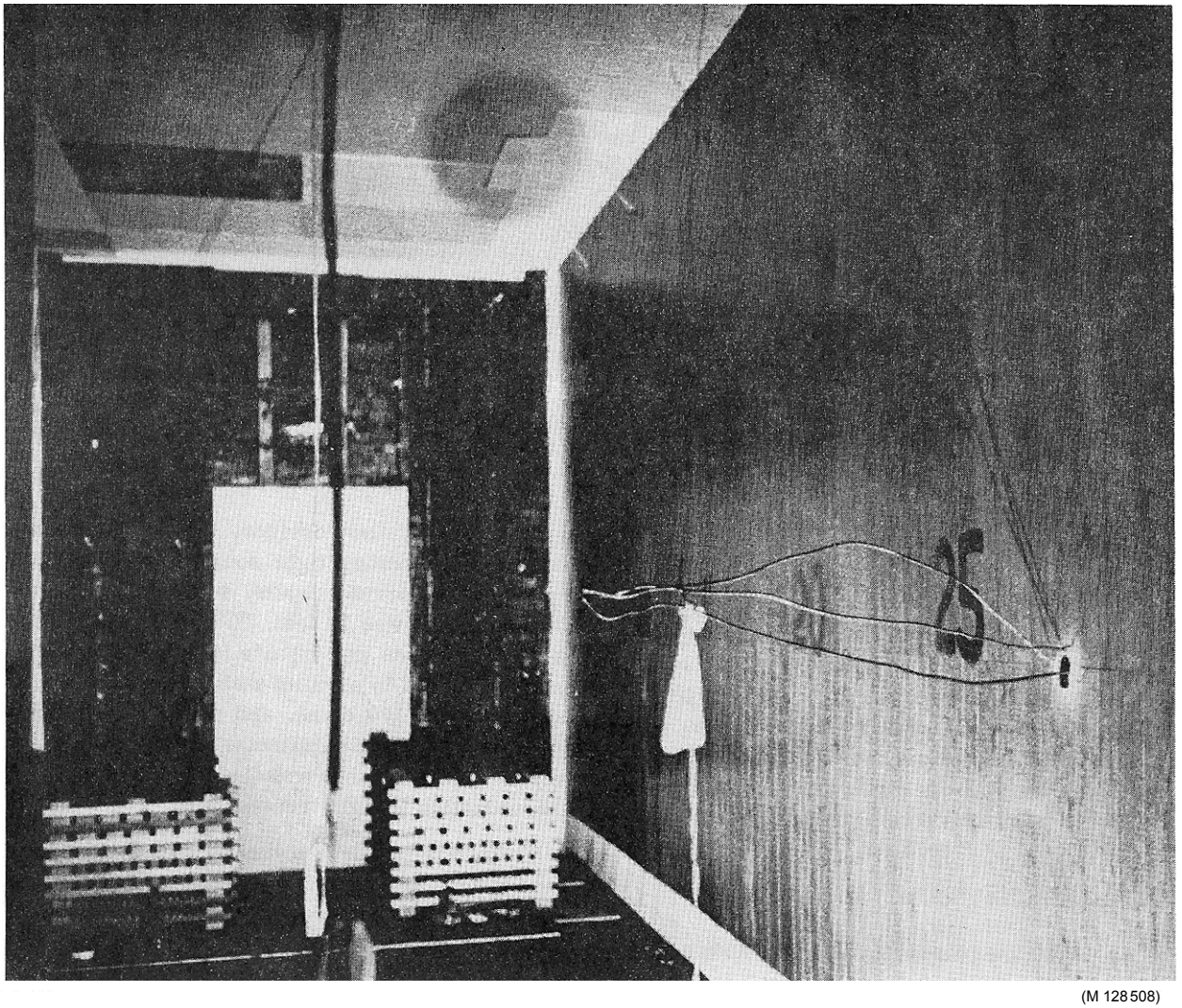

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Figure 6.--Partial view of corridor with hardboard in place on walls for Test No. 2.

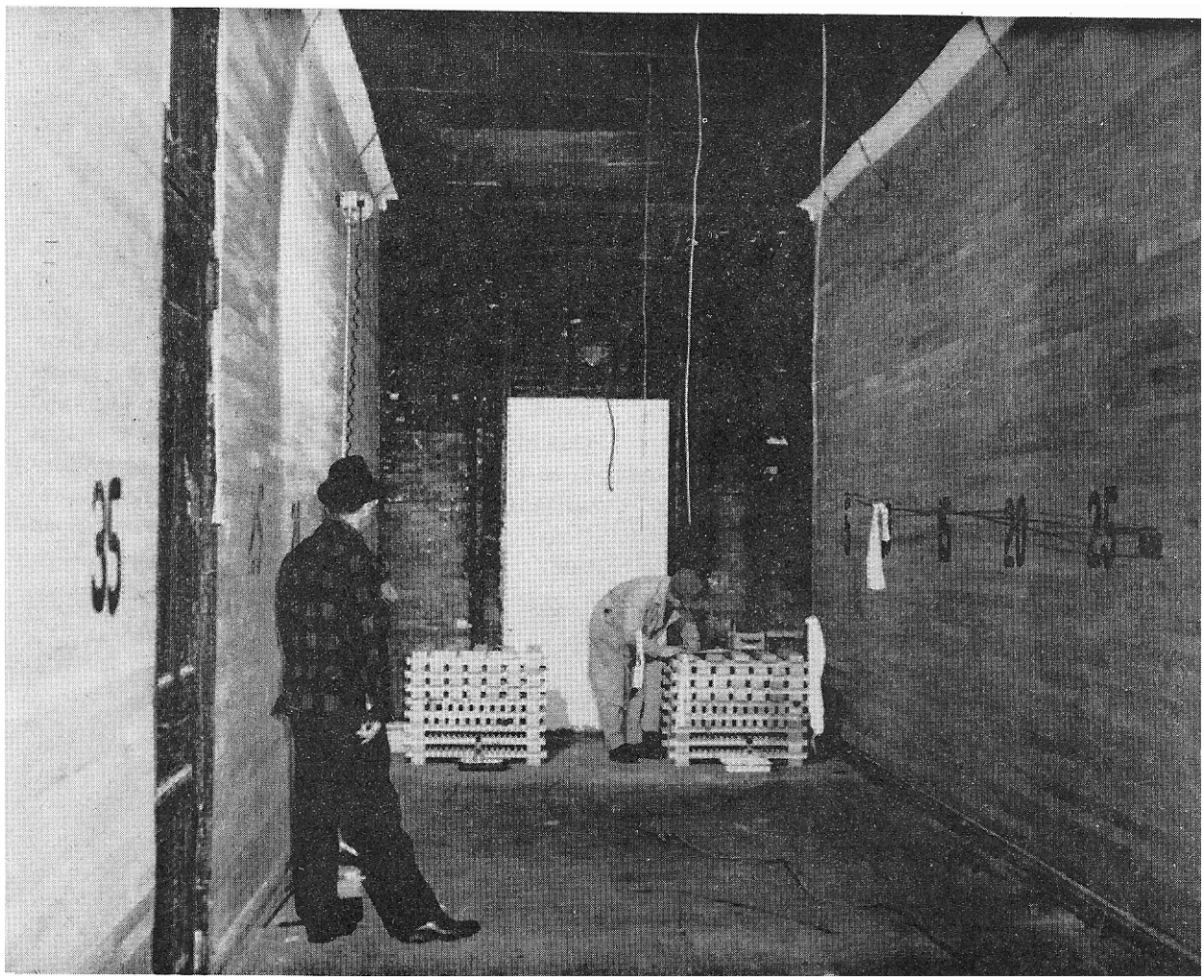

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Figure 7.--Photograph of fire exit end of corridor showing walls constructed of red oak flooring, and wood ignition cribs in place. (Test No. 3)

INSTRUMENTATION

Temperature-Recording Equipment

Iron-constantan thermocouples were placed at 36 locations in the corridor for each test (figs. 8 and 9). Twenty-four of the thermocouples were connected to an automatic 24-point recording potentiometer and the other 12 to a switch box and single-point dial potentiometer.

Smoke Density Equipment

Two selenium-photovoltaic cells and corresponding light sources were placed 5 feet above the floor at distances of 28 and 50 feet from the ignition end of the corridor. The photocells and their corresponding light sources were mounted on opposite corridor walls, so that the distance between them was 12 feet. Photocell illumination was 100 lumens per square foot. Each photocell was connected in parallel with a variable resistance of 0 to 100 ohms, and photocell response was read on a millivoltmeter. Voltage reduction across the resistance was directly proportional to the reduction in light transmission.

To keep the surface of the photocells free from tars and to lower their temperature, small electric fans were installed behind the photocells. Thermometers were placed at each photocell location and when the temperature exceeded 200° F., the photocell was removed from service.

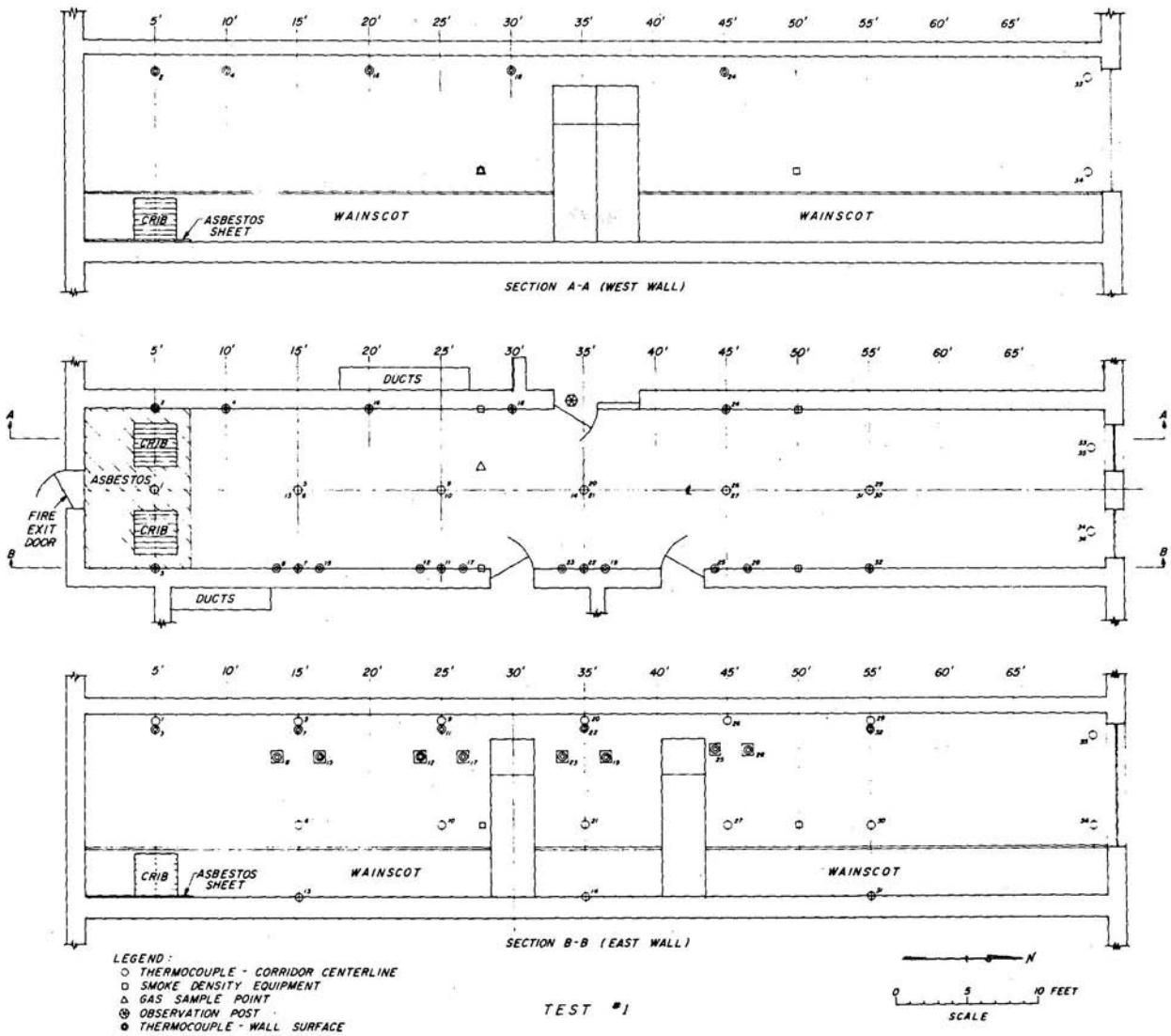

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Figure 8.--Drawing of original corridor, showing placement of thermocouples and test devices for Test No. 1.

Gas Analysis Equipment

Gas samples for analysis were collected through copper tubing extending from the interior of the corridor (at a point 5 feet above the floor and 28 feet from the ignition end of the corridor) to an adjacent room. Two systems were utilized for the analysis of gas samples. One system employed three direct-reading instruments to analyze for oxygen, carbon dioxide, and carbon monoxide. The instruments for oxygen (0-21 percent) and carbon dioxide (0-20 percent) analysis were of the liquid-absorption displacement type (fig. 10), and the instrument for carbon monoxide (0-1.5 and 0-10 percent) analysis was of the absorption colorimetric type (fig. 11). Appropriate aspirator bulbs or a direct pump plunger were used in transferring the sample from the corridor through the sampling tube to the analyzers. The other system which was used only in Tests Nos. 2 and 3, consisted of a 350-cubic centimeter-glass sampling tube equipped with valves at both ends and a vacuum pump. Gas samples were taken with this equipment every 3 minutes and later analyzed at the Laboratory by means of gas chromatographic techniques.

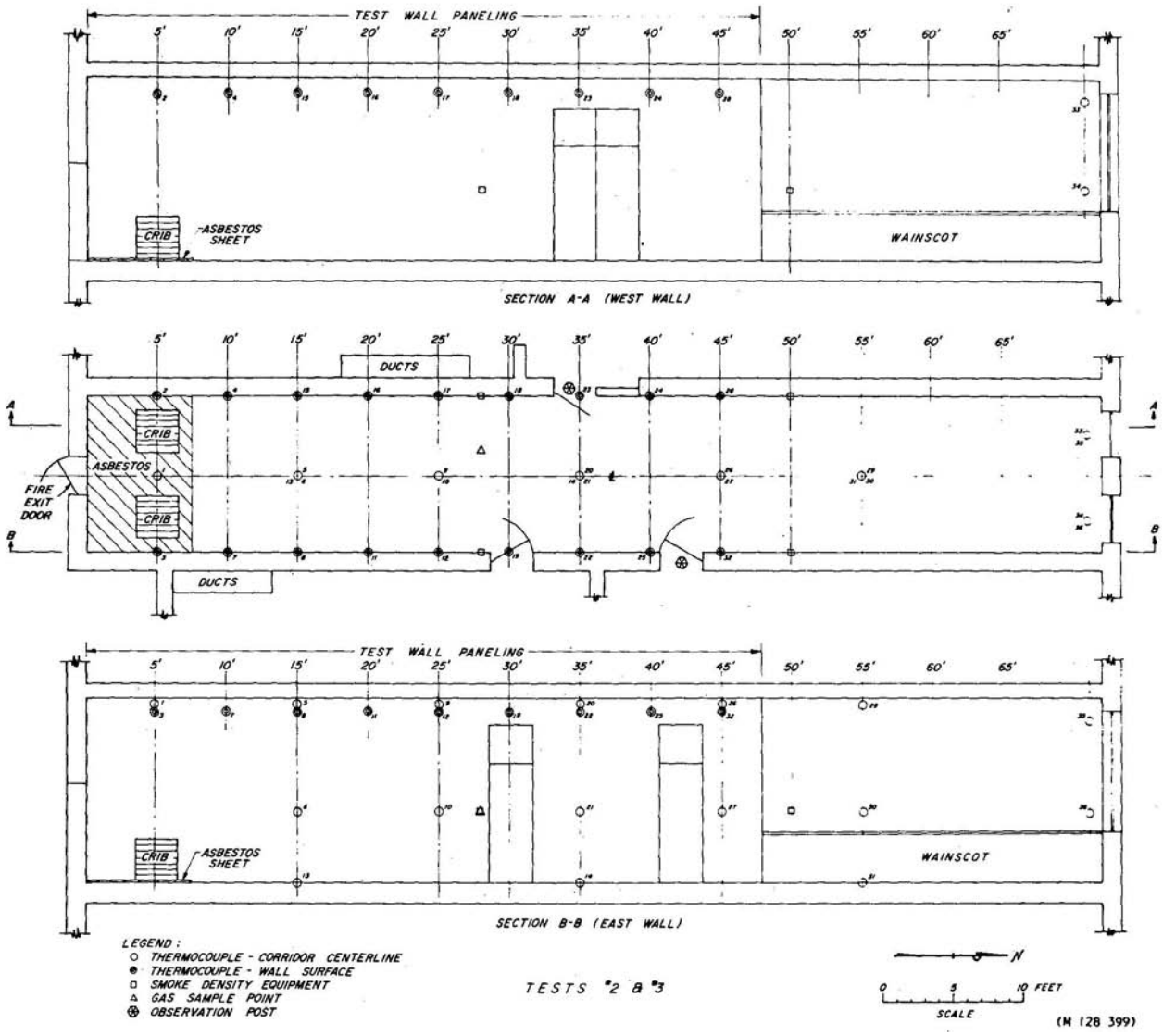

Figure 9.--Drawing of corridor showing placement of hardboard and red oak paneling, thermocouples, and test devices for Tests Nos. 2 and 3.

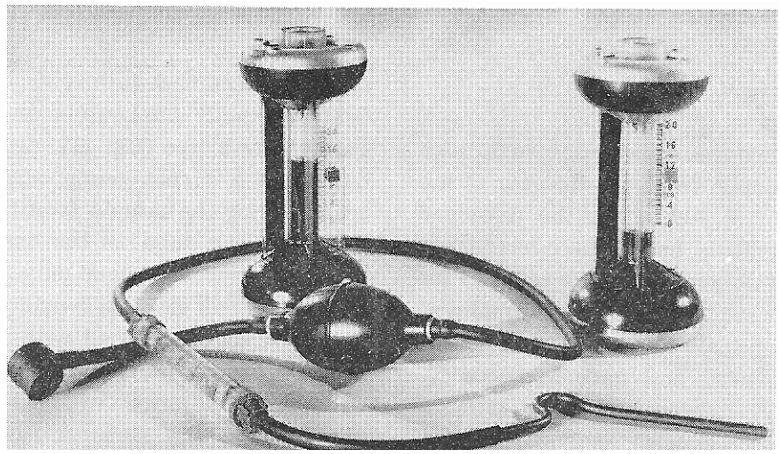

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Figure 18.--Liquid-absorption displacement type instruments for the analysis of gases for oxygen and carbon dioxide content.

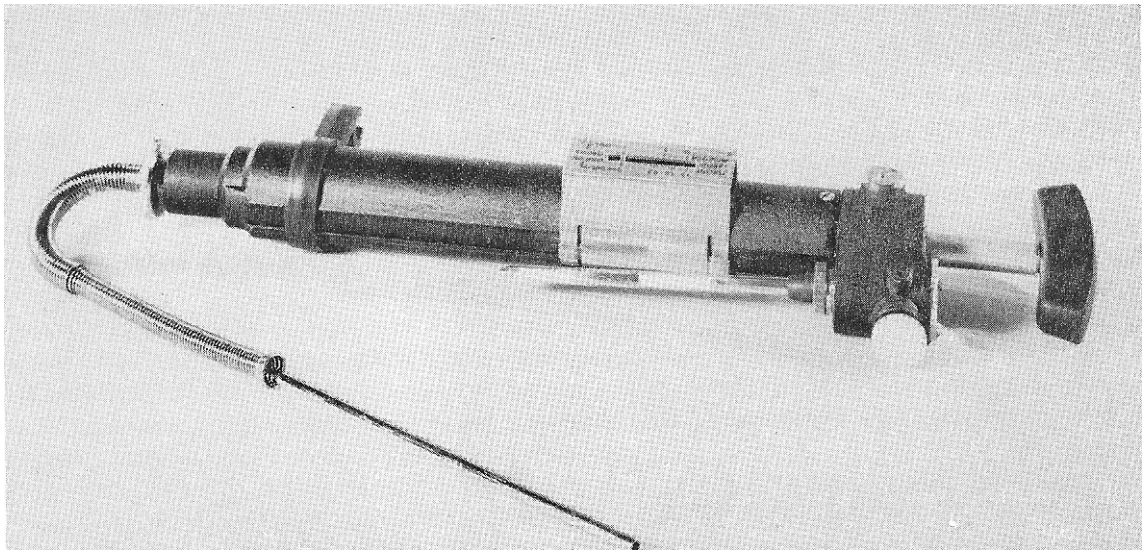

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Figure 11.--Adsorption-colorimetric type instrument for the analysis of gasses for carbon monoxide content.

Environmental Equipment

Thermometers were used to determine outdoor and indoor temperatures and a sling psychrometer was used to measure relative humidity.

An integrating-cup anemometer was placed in the open, approximately 200 feet from the test building and 5 feet above the ground surface, to determine the average wind velocity for a 1/2-hour period before the tests.

Miscellaneous Equipment

A resistance moisture meter (1-inch prong type) was used to measure the moisture content of the wood cribs.

A portable dictaphone was used by the main observer to rapidly record observations during the test conduction.

TEST PROCEDURE

Fire Load

Tests conducted by the Los Angeles Fire Department (5)[3] and the National Research Council of Canada (8) indicated that-two wood cribs, each of 200- to 350-pound weight, could create ASTM E119 time-temperature conditions within a corridor. Those cribs were constructed of 1/2- by 1/2-inch to 2- by 4-inch material.

From the results of the preceding tests, it was decided to use two 250-pound cribs constructed of Douglas-fir, 1 by 1 inch to 2 by 4 inches in cross section. Details of the wood cribs are shown in figure 12. Overall crib dimensions were 3 by 3 by 2.5 feet.

Both cribs were placed on an asbestos pad, and their centers were 5 feet from the end of the corridor. One edge of each crib was 1 foot from the wall (figs. 8 and 9).

The cribs were ignited by ethyl alcohol placed in a pan beneath each crib. Test time commenced upon ignition of both cribs.

Test Preliminaries

Immediately before each fire test the two windows at the far end of the corridor were opened halfway (fig. 4) to provide a source of air and to endeavor to maintain atmospheric pressure within the corridor. The total vent area provided by the open windows was 28 square feet.

The moisture content of each crib was randomly measured with a prong type, resistance moisture meter and the average of five readings was taken

[3] Underlined numbers In parentheses refer to Literature Cited at the end of this report.

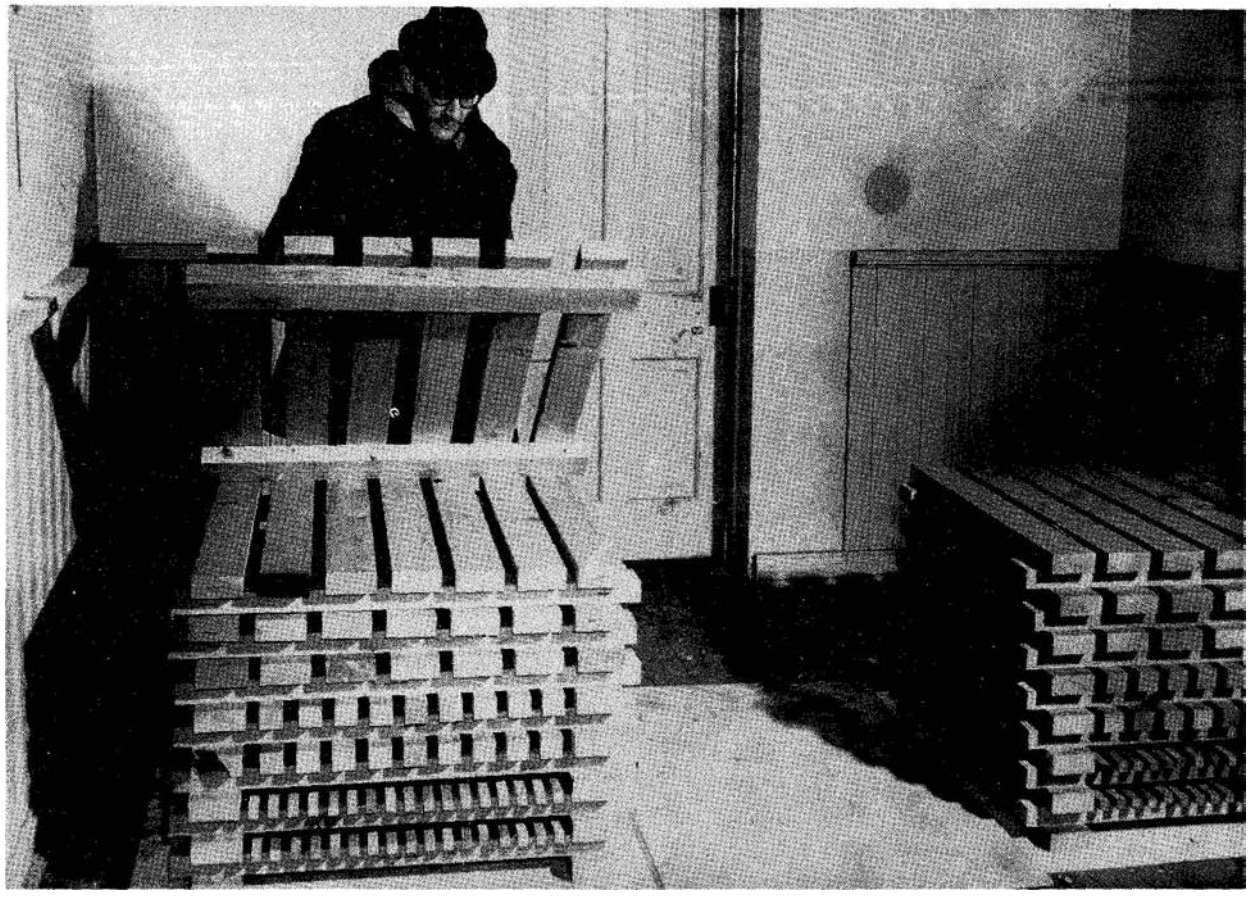

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Figure 12.--Details of wood cribs used in developing fire exposure.

as the effective moisture content for each.

Outdoor temperature, corridor temperature, wind velocity,, and wind direction were recorded. Relative humidity was also recorded when temperatures were above freezing.

General Procedure

Pans containing 500 cubic centimeters of 95-percent ethyl alcohol were centered beneath the two wood cribs and ignited simultaneously. All timing was initiated and recording equipment started upon a single command when the alcohol under both cribs had ignited. Gas samples were collected throughout the test runs.

One person, observing the corridor through a small hole in the west wall door, recorded the progress of the fire with the aid of a portable dictaphone. A second observer was stationed at an east door.

Tests were ended at the discretion of the principal observer and an expert firefighting supervisor. The end of each test was signalled by the extinguishing of the fire by firefighting personnel.

After the fire was extinguished and the corridor cleared of smoke, the walls were inspected and the degree of decomposition recorded. The remainder of each crib was collected for subsequent drying and reweighing.

TEST RESULTS

Presentation of Data

For comparative purposes the corridor conditions for each fire exposure study are summarized in table 1, along with data on environmental conditions, wood cribs, and gas analyses obtained during each test, Detail observations made during and after each fire exposure study are given in table 2. The complete temperature data for the three studies are presented in the Appendix (tables 3-15).

The data for the three studies are further analyzed and compared in curve form in the

following illustrations:

Figure 13. --Relationship of ceiling temperatures above the wood cribs to the ASTM E119 time-temperature curve.

Figure 14.--Reduction in light transmission during the progress of each test.

Figure 15.--Average temperatures obtained along the center of the corridor 5 feet above the floor level during each test.

Figures 16, 17, and 18.--Minimum-maximum temperature envelope curves obtained along the west wall, east wall, and center of ceiling, respectively, during each fire exposure.

Figure 19.--Average temperatures obtained directly in front of the open windows.

Discussion of Results

Early observations near wood cribs.--The fires generated by the two 250-pound wood cribs generally reached a height of about 8 feet at 2-minutes elapsed time, 10 feet at 3 minutes, and to the ceiling at 4 minutes. Following an initial delay of about 1-1/2 minutes, the temperatures developed at the ceiling just above the cribs (fig. 13) generally followed the ASTM E119 curve for the next 4 or 5 minutes. The delay time for the red oak test was only about 1 minute and the temperatures were slightly higher, in general, than for the other two tests.

There was ignition of the wainscoting near the crib fire at the 5- to 6-foot wall mark in the first test at 4 minutes and some burning of the paint on the wall above the burning wainscoting at 4-1/2 minutes. The hardboard paneling in the second test had darkened in color during this length of exposure, but had not ignited. In the third test, with the red oak paneling, there was ignition of the red oak near the crib at 4 minutes and the flames had spread upward to the ceiling and along the corridor wall for about 12 feet at 4-1/2 minutes. By 5 minutes, there was some flaming over the red oak paneling near the ceiling out to a distance of about 25 feet.

Flashover.--In all three tests, flashover occurred in 6 to 7 minutes after crib ignition but before flames had spread any appreciable distance along the walls. In fact, the hardboard paneling had not even ignited at the lower levels when flashover occurred. Apparently, the oxygen supply in the immediate vicinity of the cribs was insufficient to permit the gases to ignite. The hot, combustible gases progressed down the corridor, flaming only as they reached sufficient quantities of oxygen.

In each of the tests, the flaming of the cribs was momentarily reduced immediately after flashover. Then gradually, crib flaming was re-established, including flaming of combustibles (wall linings, doors, trim, and exposed woodlath) throughout the corridor.

Smoke development.--In each test, a very dense smoke condition developed throughout the corridor immediately following flashover. It will be seen in figure 14 that a reduction in lighttransmission was occurring from the beginning of the tests. The smoke liberation, as evidenced in figure 14, was greatest for the corridor "as constructed," less for the red oak test, and least for the hardboard test when considered on the same time basis. Since the tests were conducted during the winter and the building was unheated, the corridor materials had a fairly high moisture content; hence, some of the 'smoke" in the first test may have been steam generated as a result of this high moisture content. In the third test (red oak), it was necessary to cease observations shortly after flashover, as dense smoke developed. At this time wind draft conditions caused smoke to filter out of the corridor into the adjoining west observation room.

Light transmission.--Light transmission, measured by the photocells, was not in direct relation to the visibility within the corridor. In several instances, the observers were able to continue observations while the photocells indicated less than 10 percent light transmission. Assuming that the light transmitted through the smoke-laden atmosphere obeys the Beer-Lambert law

$$I = I_o \exp\left\{-Kcl\right\}$$

where I = incident flux

I_o = transmitted flux

K = attenuation coefficient

c = smoke concentration

l = light path length

then a reduction of light transmission to 10 percent of the original corresponds to a smoke concentration of 33 percent of the atmosphere, and a reduction to 1 percent corresponds to a smoke concentration of 66 percent. The Beer-

Table 1.--Description of corridor for each fire test and comparative data on environmental conditions, wood cribs, and gas analyses for each test

Date	Time p.m.	Corridor description	Environmental conditions[1]				Wood cribs				Gas analyses						
			Temperature		Wind		Crib No.	Moisture content (av.)	Weight		Elapsed time	Direct analysis			Chromatographic[2]		
			Out-door	In-door	Direction	Velocity (av.)			Before test	After test		O_2	CO_2	CO	O_2	CO_2	CO
			°F.	°F.		M.p.h.		Pct.	Lbs.	Lbs.	Min.sec.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.
		Initial Test:					TEST NO. 1										
Dec. 12, 1964	2:00	Corridor in "as is condition" with varnished white pine wainscot extending around the perimeter for a height of 3 feet 6 inches; flat-painted plaster walls and ceiling; and slate blackboards above the wainscot for a 20-foot distance from the windows.	24	28	S.W.	2.8	1	9.5	250	190[3]	5:00	16					
							2	10.5	250		6:15			0.3			
											11:00	5.3					
											13:00			0.3			
											17:00	9					
		Eight 1-foot-square test panels, with a thermocouple on the surface of each, were attached to the east wall 3 feet below the ceiling:															
		Test panel material / No. of test panels / Thermocouple No.															
		Wood-grained hardboard / 4 / 8,17,23, and 28															
		Fiberboard / 2 / 12 and 19															
		Red oak / 2 / 15 and 25															
		Hardboard Test:					TEST NO. 2										
Dec. 30, 1964	1:30	West wall: 1/4-inch thick, dark walnut, prefinished wood-grained hardboard to 48 feet from ignition end of corridor.	34	38	S.	9.2	1	10	250	179.5	0:00				20.4	0.8	0.0
							2	10	250	177.5	3:00				15.7	4.1	.05
											3:15	0.0		0.15			
		East wall: 1/4-inch-thick, light (blond), prefinished wood-grained hardboard to 48 feet from ignition end of corridor.									5:00	3.5					
											6:00				4.4	12.5	10.6
											6:30	17.6		4.5			
											8:15			7.0			
		Surface flammability indices:									9:00	16.6			9.9	8.3	8.2
		122 (8-foot tunnel)									10:00			10.0			
		123 (ASTM E162 radiant panel)									11:30	17.7					
		157 (ASTM E84 large tunnel)									12:00				6.5	11.8	10.3
		88 (corner-wall test)															
		Red Oak Test:					TEST NO. 3										
Jan. 22, 1965	1:00	Both walls covered for a 48-foot distance with 25/32-by 2-1/4-inch red oak flooring. The flooring was nailed to strips originally used to support lath and plaster.	34	35	E.	11.2	1	9	250	153.5	0:00	20	0.0	0.0			
							2	9	250	150.5	1:30			0.1			
											2:05	20					
											3:00				20.7	0.8	0.0
											4:05		3.5				
											4:40			0.5			
		Surface flammability index = 100.									5:30	8					

[1]Humidity readings were not taken for tests Nos. 1 and 2 as outside temperature was below or near freezing. Humidity reading for test No. 3 was 95 percent.
[2]Gases collected at site and later analyzed with gas chromatographic equipment.
[3]Total of two cribs.

Lambert law has been found to apply to transmitted light within certain ranges of mass concentrations (3), but it is questionable whether it applies equally well to light scattering. More research is required in this area.

Following flashover and the development of dense smoke, visibility improved and there was reignition of the cribs and burning of the combustible materials on the side walls. During the first test, which was allowed to progress for 18 minutes, there was a second flashover at 15 minutes after initial ignition. This was also followed by the development of dense smoke. Visibility improved and reignition was occurring again just as the corridor fire was extinguished. The light transmission during the progress of each test is shown in figure 14.

Gases.--Among the factors that influence the survival of occupants within a burning structure are the gas concentrations present in the atmosphere. Ten-percent oxygen is considered the lower limit necessary to sustain life. Below this value, death will occur in a relatively short period of time (7). Actual effects of oxygen deficiency on humans has also been noted by Coleman (1), who states the following:

> At an oxygen level of 17 percent, a candle is extinguished;
>
> At 10 to 14 percent, respiration is affected;
>
> At 6 to 10 percent, nausea occurs;
>
> And levels from 0 to 6 percent are fatal.

Certain levels of carbon monoxide are also assumed to be fatal to human occupants. Minchin (6) reports that collapse will occur when the product of average carbon monoxide level in percent, K_{co}, and exposure time in minutes, t, equals 4.5. If this is assumed to be valid, then human life will be lost when

Table 2.--Detail observations made during individual lire tests and upon completion of each test

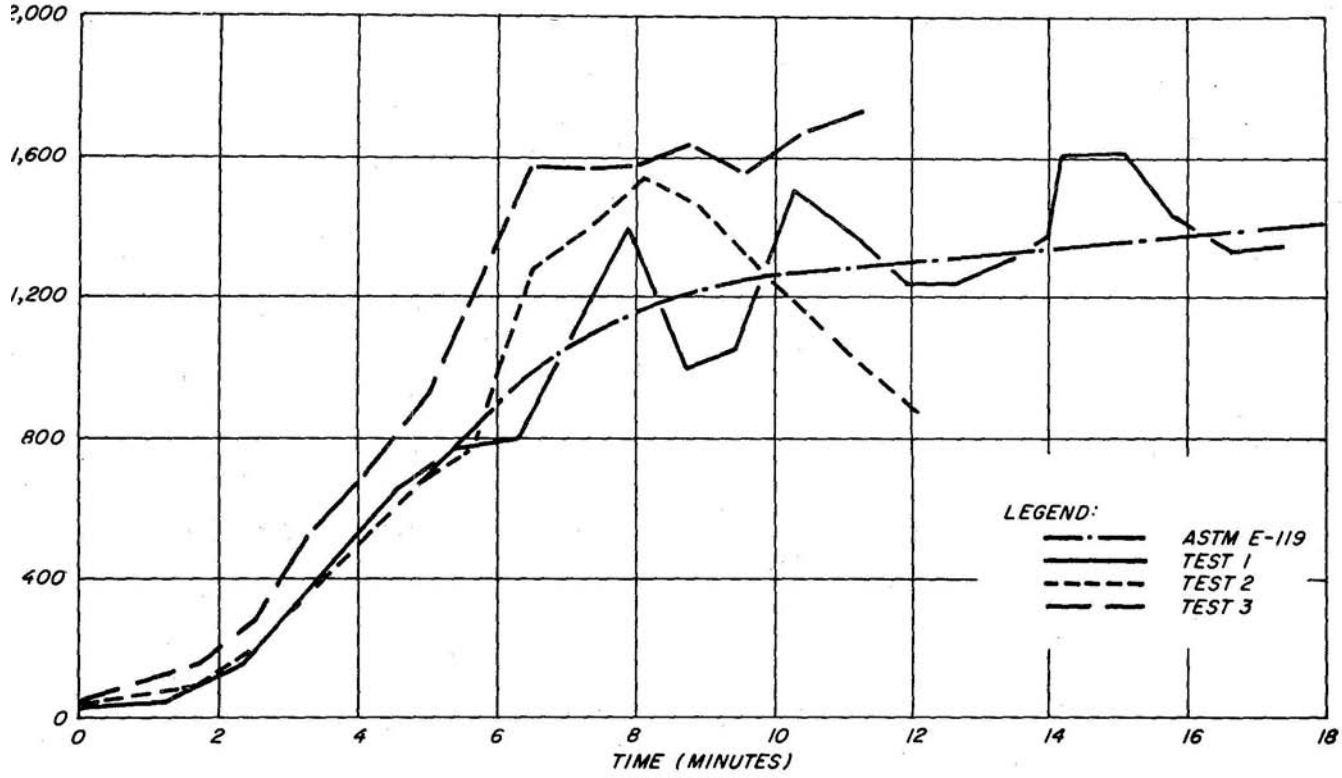
Test No. 1		Test No. 2		Test No. 3	
Elapsed time	Observations	Elapsed time	Observations	Elapsed time	Observations
Min.:Sec.		Min.:Sec.		Min.:Sec.	
			DURING TEST		
0:00	Left crib ignited about 10 seconds ahead of right crib.	0:00	Cribs ignited.	0:00	Cribs ignited.
1:00	Flames about 4 feet high on left crib and 2 leet high on right crib.	1:15	Crib flames about 4 feet high and some smoke filling room	1:00	Crib flames about 5 feet high.
1:30	Smoke starting to accumulate within room.	1:30	Flames 6 feet high.	2:00	Crib flames about 8 feet high.
2:00	Flames at both cribs about 8 feet high.	2:00	Flames 8 feet high and more smoke.	3:00	Crib flames about 10 feet high and very ride near base; some smoke filling room.
3:00	Flames reaching to 10-foot height, about 2 feet away from ceiling.	3:00	Flames reaching to 10-foot height, just below ceiling.	4:00	Ignition of side wall at 8-foot mark. Flames reaching ceiling.
4:00	Ignition of wainscoting at 5-foot mark in length of corridor.	4:00	Paneling very dark near crib, but no ignition. Flames reaching ceiling.	4:00	Burning of side wall--floor to ceiling. out to 12-foot mark.
5:00	ignition of paint just above wainscoting at 5-foot mark.	4:30	Flames at cribs are broadening out.	5:00	Burning on side wall near ceiling out to 25-foot mark. Heavy smoke near floor.
5:30	Flaming of wainscoting to 6-foot mark.	5:00	Paneling at 5-foot distance near cribs is very dark, but can see no flaming.	6:00	Flashover, flames reaching to feet or farther along side wall ceiling area. Most of the flames near edge of ceiling.
6:00	Photo cell removed, 28 feet from ignition end.	5:15	Very dense smoke near ceiling.	6:30	Heavy smoke, flames out, and some glow at crib.
7:00	Flames spread rapidly just below the ceiling out to a point about even with the stairway door or possibly beyond. These flames appear to so move because of a lack of oxygen In the vicinity of the crib, and these combustible gases flame only as they reach and use up available oxygen.	6:00	Flames Spread along ceiling for distance of over 50 feet; width of flames appeared to be greater than in the first test.	7:00	Heavy smoke throughout building.
7:30	Dense smoke and all flames appear to be out.	7:00	Flames are out and extremely dense smoke has developed throughout the room.	7:30	some flames developing at cribs end side walls with a second flashover along ceiling.
10:00	Reignition of crib tire. Some plaster falling in all parts of the corridor. Flames impinging on ceiling and extending out as far as the 20-foot mark.	8:00	Flames are starting to reignite at several points within room, particularly around door frames and near floor.	8:00	Heavy smoke developed and It was necessary to abandon the observation area on the rest side of corridor.
11:00	Smoke within corridor is reduced and visibility good.	10:00	Cribs are starting to reignite.	11:00	Extinguishment of fire because heavy smoke exists throughout building.
14:00	Wainscoting flaming out to the 10-foot mark.	11:00	ignition of most of wall surface.		
15:00	Wainscoting flaming at 15-foot mark. Flashover along ceiling. Photocell removed, 50 feet from ignition end.	12:00	Fire extinguished to save corridor for next test.		
15:30	High smoke density and flames appear to be out.				
16:00	Reignition of crib.				
17:00	Smoke within corridor is reduced and visibility good.				
18:00	Extinguishment of fire to save corridor.				
			AFTER TEST		
The wainscot wood was charred for a distance of 14 feet from the crib end and the varnish coating was charred for an additional 4 feet, Beyond this point, the varnish coating was in a less degraded condition as distance down the corridor increased. The plaster wall was cracked by the intense heat near the cribs, and upon rater extinguishment of crib flames, the plaster had been blown from the lath in this area. The plaster wall had also fallen away from the wood lath 50-to 65-foot distances. At the 50-57-foot distances, plaster had fallen from the ceiling and the lath was completely charred		The paneling was completely consumed for an average distance of 15 feet from the crib end of the corridor. From I5 to 45 feet the paneling was charred to depths In relative proportion to the distance down the corridor. At locations near the floor, from 40 feet on, the surface was either only slightly charred or smoke-particle coated.		The red oak paneling was charred to a depth of 3/8 inch from the celling to within 4 feet of the floor for an average distance of 30 feet from the crib end of the corridor. Beyond the 30-loot distance the depth of char was approximately 1/4 inch. The wall area from the floor to a 4-foot height was charred 1/4 inch deep in the area of the cribs with the depth decreasing as the distance down the corridor increased until 0- to 1/16-inch depth existed at the end of the paneling at the 48-foot mark.	

$$\int_0^t K_{co}\,dt = 4.5$$

Hamilton and Johnstone (4) cited that a 1.28 percent carbon monoxide level (by volume) will cause a loss of consciousness immediately.

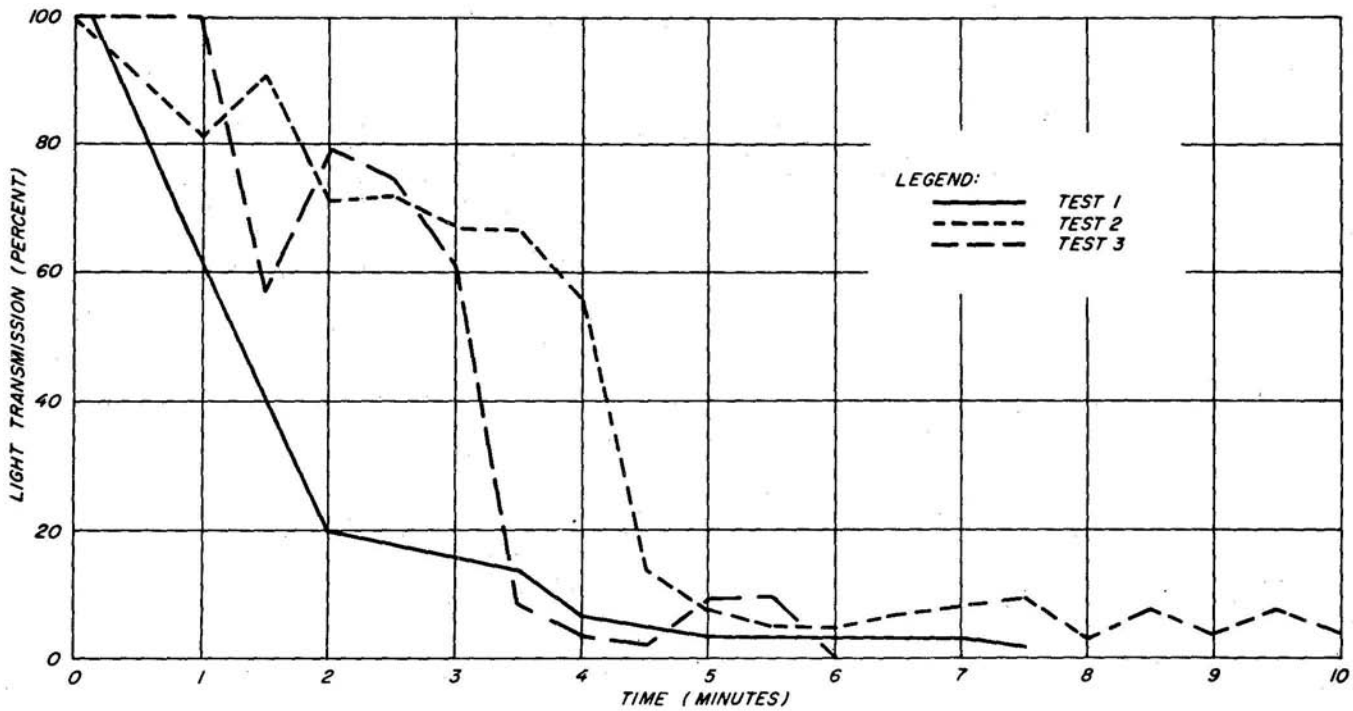
The gas analyses taken during the first test were limited to three direct-analysis determinations for oxygen and two for carbon monoxide. The analyses indicated a definite lowering of the oxygen content to 5.3 percent at 11-minutes elapsed time, but no appreciable amount of carbon monoxide was indicated in either of the determinations for that gas.

In the second test (hardboard wall paneling), more complete analyses were taken and techniques had generally been improved. Samples were taken at 3, 6, 9, and 12 minutes for later analysis of oxygen, carbon dioxide, and carbon monoxide content. Several samples were also taken for direct analysis for carbon dioxide and carbon monoxide. The oxygen determinations gave results similar to those in the first test, reaching a



(M 128 402)

Figure 13.--Relationship of ceiling temperatures above the wood cribs (No. I thermocouple) to ASTM E119 conditions during the three tests.



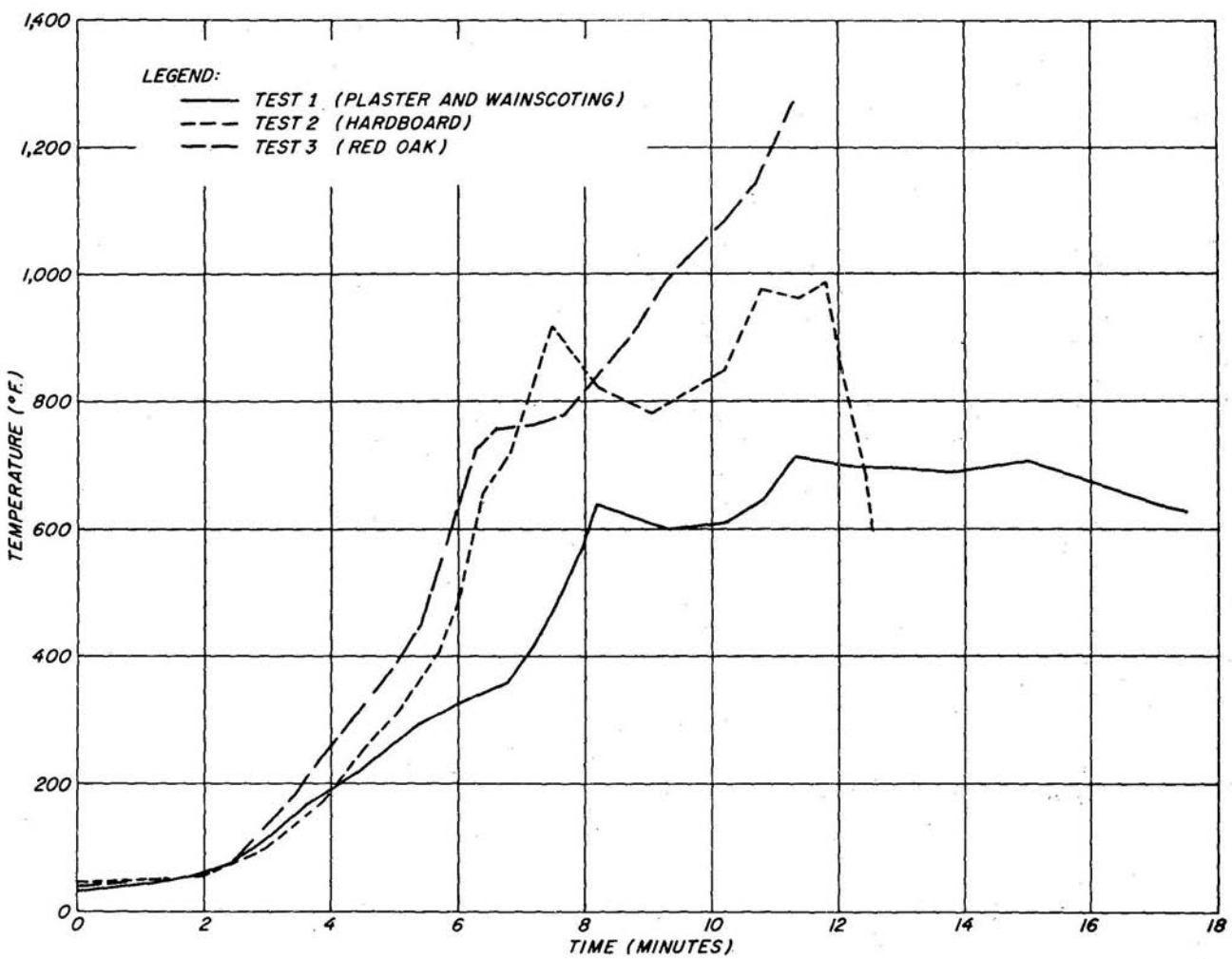
(M 128 404)

Figure 14.--Reduction in light transmission during each test.

minimum content of 4.4 percent. Determinations for carbon dioxide made by the two analysis methods did not correspond identically; but did indicate carbone dioxide levels as high as 12 to 18 percent. Following flashover, the carbon monoxide content was also questionably high--5 to 11 percent.

In the third test (red oakpaneling), gas analyses were made up to 5-1/2 minutes after start. of test, but no readings were taken after flashover and smoke development. The smoke developed in this test completely filled the room where sampling was accomplished and gas analyses were made. At 4 minutes the carbon dioxide level was 3-1/2 percent, and at 5-1/2 minutes the oxygen level had fallen to 8 percent. Before flashover in this test, the carbon monoxide content was less

In a partially ventilated corridor, such as used in these studies, it is logical that the oxygen content would decrease, because considerable quantities are used in the combustion of the wood and cellulosic materials. Carbon dioxide and water are produced by the burning when sufficient oxygen is available, but as the oxygen content is decreased, greater volumes of carbon monoxide will result. Only in the second test (hardboard paneling), were complete gas analysis data obtained. These data indicated that at 6 minutes, when the principal burning was still from the wood cribs, oxygen levels had decreased to less than 5 percent and the carbon dioxide and carbon monoxide contents exceeded 10 percent. This high percentage of carbon monoxide was not observed in the limited determinations of the first test at 6.0 and 13.0 minutes; however, minor variations in the



(M 128 398)

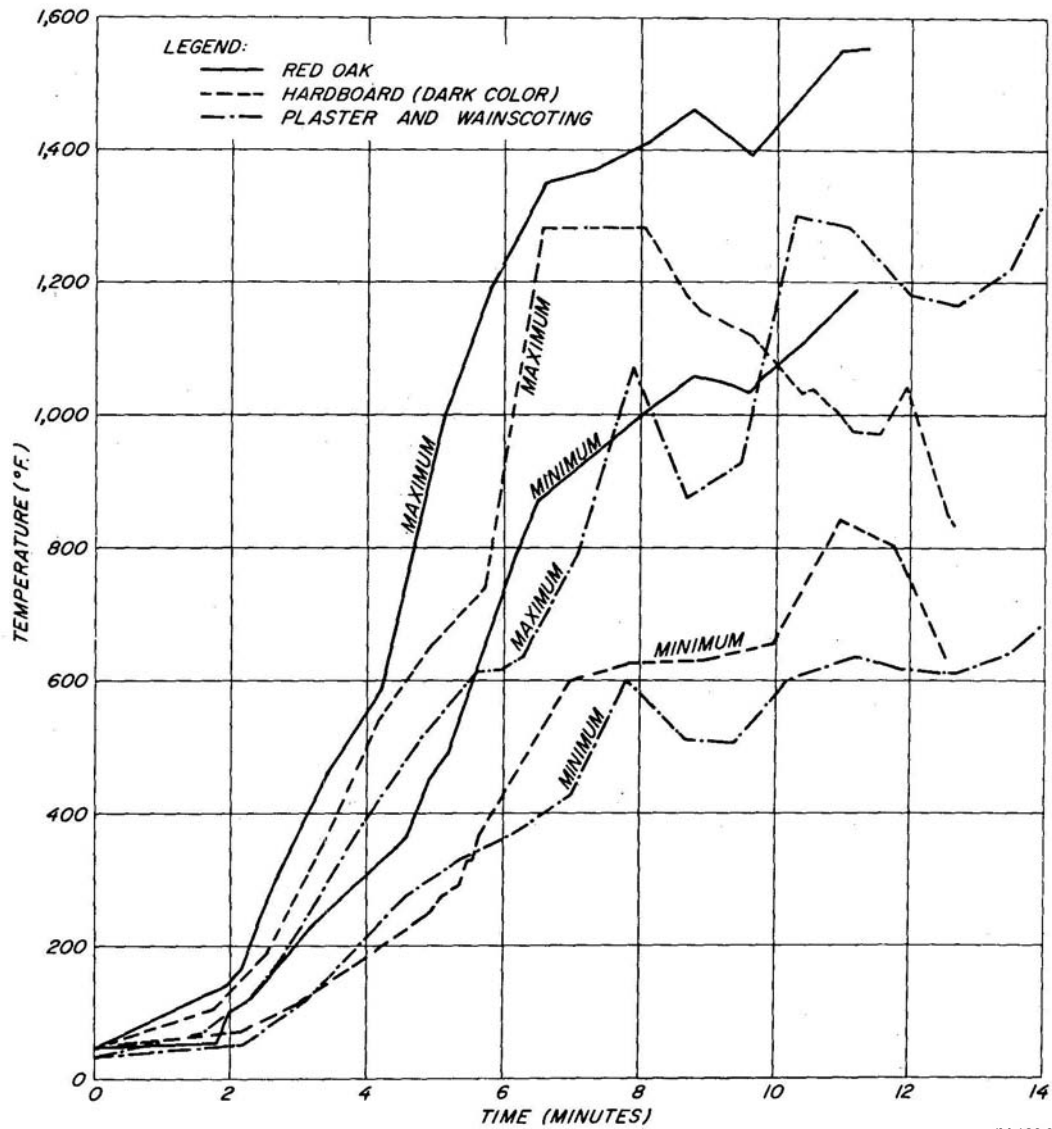
Figure 15.--Curves showing average temperatures obtained along the center of the corridor 5 feet above floor level during each test.

air supply could greatly influence this value. Further study involving a greater number of samples and improved sampling techniques would be desirable to determine the influence various types of wall coverings have on the gases formed, when a considerable portion of the combustible contents have been exposed to fire previously.

The studies conducted indicate that within 5 to 11 minutes after start of fire in a partially ventilated corridor, conditions develop which could be fatal to human occupancy because of low oxygen content, high carbon monoxide content, or both.

Heat.--Another factor influending human survival is heat, and 300' F. is considered a critical temperature (2, 8). Temperatures measured 5 feet above the floor level were fairly uniform along the entire length of the corridor (tables 3, 4, 5 of the Appendix), except for a few fluctuations indicated by the thermocouple nearest the crib fire. The average temperature curves at the 5-foot level along the corridor, for all three tests, are shown in figure 15. It will be noted that the average temperature exceeded the critical to life level of 300° F. at 5.6, 5.0, and 4.3 minutes in tests 1, 2, and 3, respectively.

The floor temperatures (tables 12-14 of the Appendix) were high throughout the tests, with readings as high as 350° to 400° F. at a distance



(M 128 382)

Figure 16.--Minimum-maximum temperatures obtained along the west wall during each fire exposure test.

of 55 feet from the ignition end of the corridor at the conclusion of the test.

The minimum-maximum temperatures measured along the sidewalls and ceiling (figs. 16-18 and tables 6-11) generally showed that the highest temperatures were generated during the third test (red oak) and the lowest during the first test of the corridor as originally constructed. In general, maximum temperatures represent those at the crib end and minimum temperatures those at the window end of the corridor. Ceiling and wall temperatures exceeding 1300° F. were recorded before the tests were ended. Minimum sidewall temperatures of 600° to 800 ° F. were recorded during the "as constructed" and hardboard tests, but the minimum ceiling and sidewall temperatures in the red oak test exceeded this temperature range.

The temperatures directly in front of the two half-open windows, measured 5 feet above the

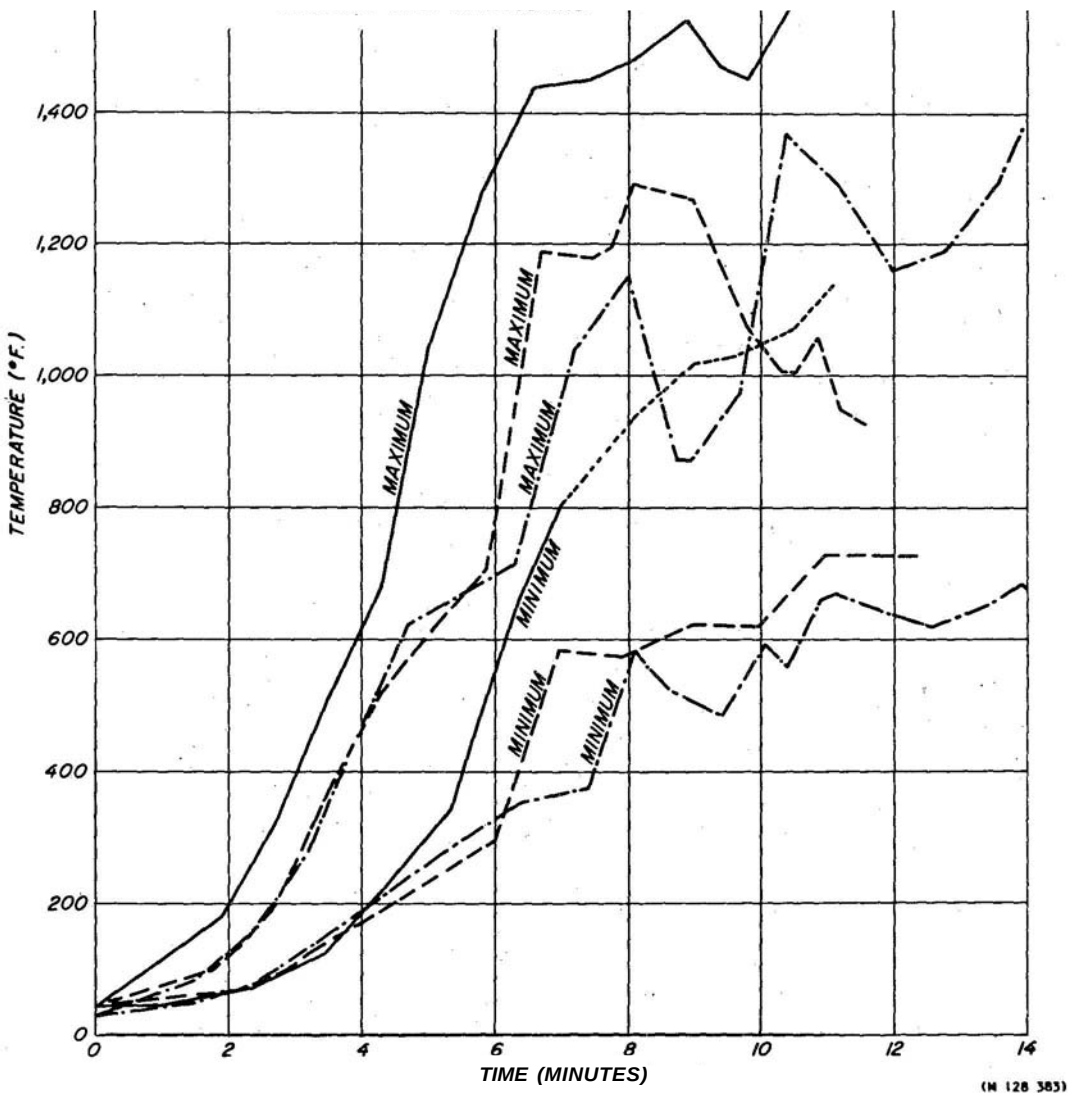


Figure 17.--Minimum-maximum temperatures obtained along the east wall during each fire exposure test.

floor (fig. 19), generally increased throughout the tests and there was no evidence of any appreciable amount of cool outside air entering through the windows.

The ignition specimens (with thermocouples attached) placed on the sidewall in the first test showed a decided temperature rise at about 7 minutes (table 15 of Appendix), and then again at 14 to 15 minutes--the approximate time of the flashovers. Temperatures, however, decreased immediately afterwards, thus failing to indicate ignition or burning of these specimens; also, a comparison of ignition specimen temperatures to the corresponding wall temperatures did not indicate ignition. The ignition specimens were therefore omitted in the second and third tests.

Flame spread.--Since flames generally did not proceed along the length of the wall surfaces prior to flashover along the ceiling, it is difficult to correlate the flame-spread characteristics of wall panel materials to the fire conditions within the corridor. The red oak flooring--flame spread of 100--had burned only to a distance of about 12 feet along the wall and to 25 feet near the ceiling when the flashover occurred along the ceiling. Hardboard paneling--flame spread of 122 to 157 by several test methods, and 88 by the corner-wall test (9) (in which time to ignition is an important factor)--did not even ignite prior to flashover. During the first test, the low wood

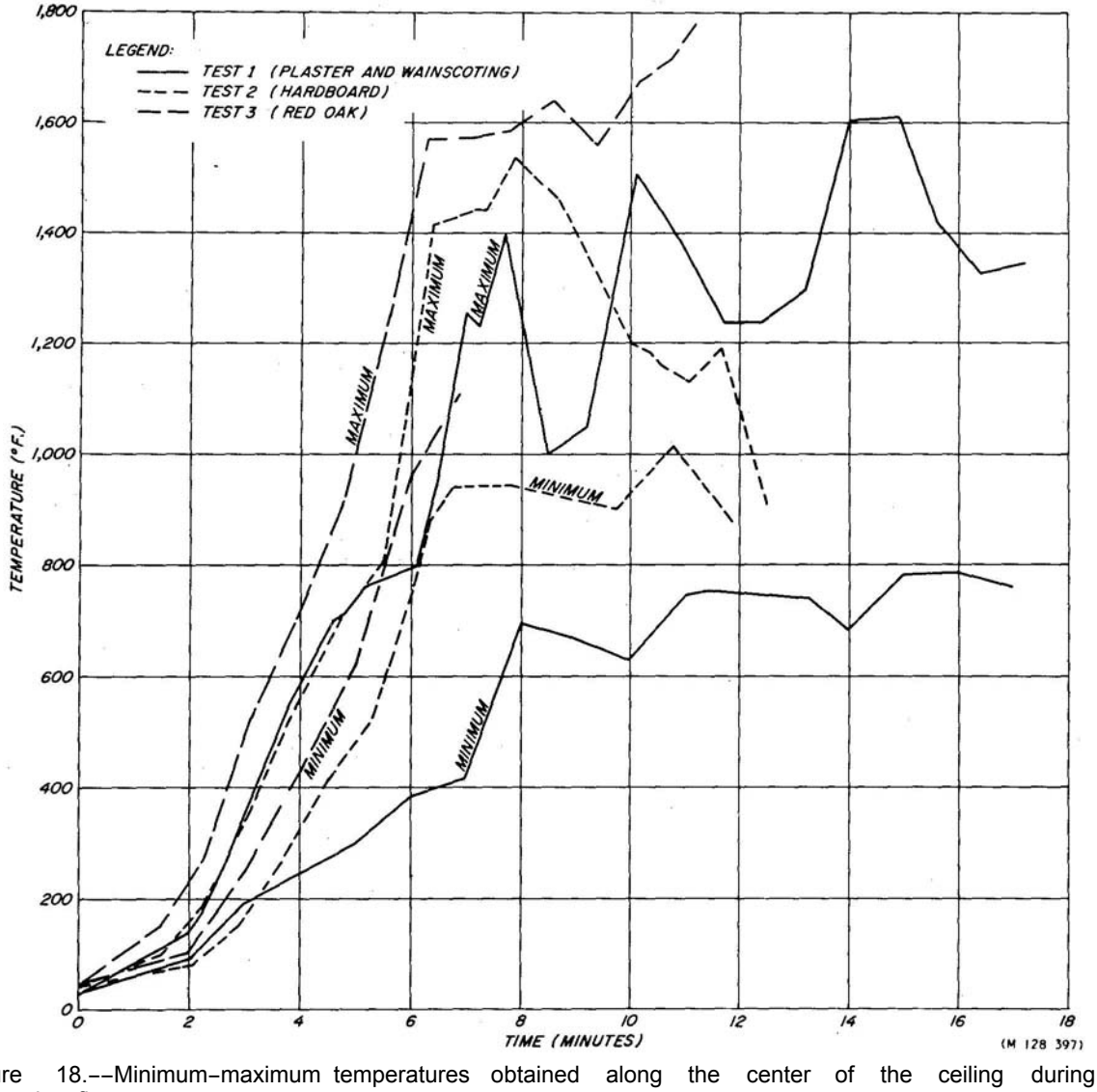


Figure 18.--Minimum-maximum temperatures obtained along the center of the ceiling during each fire exposure test.

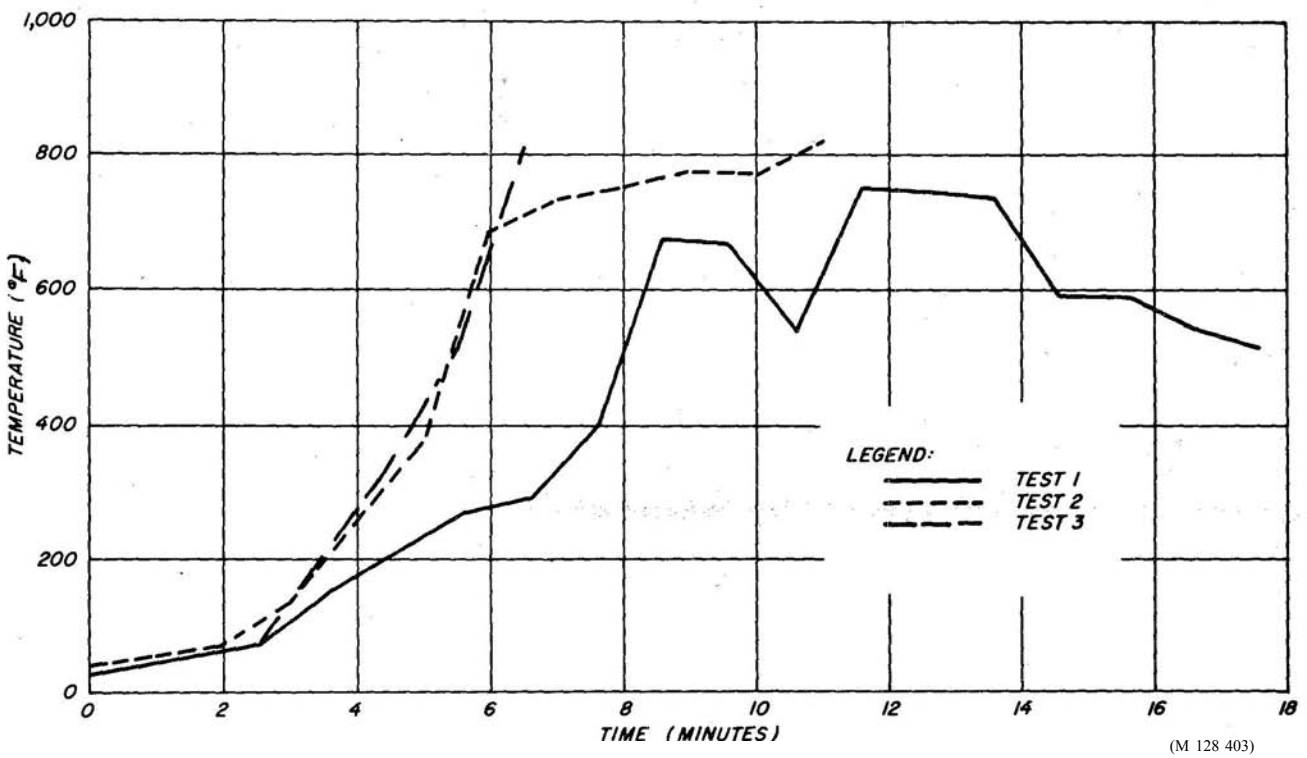


Figure 19.--Curves showing average tempertures (average of two thermocouples, Nos. 34 and 36) in front of the wondows during each test.

wainscoting did ignite but burned only for ab-foot distance before flashover occurred along the length of the ceiling.

Wood cribs.--The consumption of the wood cribs in the first, second, and third tests was approximately 310, 140, and 200 pounds, respectively, Excluding the first 1-1/2 minutes of exposure, the crib consumption rates were approximately 18 to 20 pounds per minute in the first and third tests, and about 14 pounds per minute in the second test, No significance can be placed on the lower consumption rate in the second test, as complete salvage of the material was difficult after extinguishment of the fire. The data do indicate, however, that a relatively low burning rate can result in a flashover condition in a comparatively large room or corridor.

CONCLUSIONS

Conclusions drawn from observations and data obtained during the three fire exposure studies in a partially ventilated corridor are as follows:

1. Fires generated by two 250-pound open wood cribs will develop, after 1 to 1-1/2 minutes delay, ceiling temperatures above the cribs corresponding to ASTM E119 time-temperature conditions for the next 4 to 5 minutes.

2. Within 6 to 7 minutes after ignition of the crib fires, oxygen in the immediate vicinity becomes depleted and the hot, combustible pyrolysis products flame farther outward, resulting in ceiling flashover.

3. Flashover, which is a source of additional heat and ignition of combustible materials quite distant from the fire, occurs at approximately the same time whether combustible or noncombustible wall linings are used.

4. Flashover can occur prior to any appreciable flame spread over the combustible wall linings and, in the case of hardboard linings, without the lining igniting.

5. Several flashovers may develop during a fire, dependent upon the amount of air entering the corridor and the duration of burning.

6. Visibility is generally good during the vigorous burning of the wood cribs, but immediately after each flashover dense smoke develops making observations impossible.

7. Within 6 minutes after ignition of the wood cribs, oxygen levels within the corridor decrease to less than 10 percent, carbon monoxide levels may increase to more than 10 percent, and temperatures 5 feet above the floor rise above 300° F.--any or all of these conditions making human occupancy untenable.

LITERATURE CITED

(1) Coleman, E. M.
1959. Physiological effects of some gases which may occur in fires. Plastics, Vol. 23(10):416-418.

(2) Corson, R C., and Lercos, W. R.
1951. Life hazard tests on wood interior finish. Factory Mutual Laboratories Rpt. No. 11975, Boston, Mass.

(3) Foster, W. W.
1959. Attenuation of light by wood smoke. British Jour. Applied Physics, Vol. 10(9):416-420.

(4) Hamilton, A., and Johnstone, R T.
1945. Industrial toxicology. Oxford University Press, New York.

(5) Los Angeles Fire Department.
1961. Operation school burning, No. 2. Natl. Fire Protection Assoc., Boston, Mass.

(6) Minchin, L. F.
1954. Mild carbon monoxide poisoning as an industrial hazard. Ind. Chem. Vol. 30:381.

(7) National Fire Protection Association.
1952. Fire gas research report. Committee on Fire Gas Research. NFPA Quarterly, Vol. 45:280.

(8) Shorter, G.W., McGuire, J.H., Hutcheon, N.B., and Legget, R. F.
1960. The St. Lawrence burns. Natl. Fire Protection Assoc. Quarterly, Vol. 53 (4):300-316.

(9) U.S. Forest Products Laboratory.
1959. Fire test methods used in researchat the Forest Products Laboratory. Forest Products Lab. Rpt. 1443 (Revised).

APPENDIX A

Tables 3–15.--Detail Temperature Data Obtained During the Fire Exposure Studies

Table 3.--Temperaturedata obtained at 5-foot height along center of corridor during Test No. 1[1]

Thermocouple 6		Thermocouple 10		Thermocouple 21		Thermocouple 27		Thermocouple 30		Thermocouple 34		Thermocouple 36	
Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.
Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.
0	30	0	30	0	30	0	42	0	42	0	42	0	38
1.8	40	2.6	60	3.0	85	1.1	50	1.3	50	1.5	50	1.7	52
2.5	55	3.4	120	3.8	170	2.1	82	2.3	80	2.5	75	2.7	80
3.3	105	4.2	215	4.6	255	3.1	155	3.3	170	3.5	145	3.7	165
4.2	210	5.0	290	5.2	325	4.1	165	5.3	295	5.5	275	5.7	265
4.9	285	5.8	340	6.1	360	5.1	320	6.3	365	6.5	320	6.7	265
5.6	350	6.6	370	7.0	390	6.1	390	7.3	395	7.5	405	7.7	390
6.4	380	7.4	520	7.7	590	7.1	405	8.3	680	8.5	675	8.7	680
7.3	525	8.3	555	8.5	520	8.1	700	9.3	670	9.5	670	9.7	670
8.0	595	9.1	500	9.3	480	9.1	670	10.3	610	10.5	550	10.7	535
8.9	500	9.8	515	10.2	570	10.1	660	11.3	755	11.5	755	11.7	750
9.7	500	10.6	620	10.9	620	11.1	750	12.3	745	12.5	745	12.7	745
10.5	660	11.4	640	11.7	610	12.1	755	13.3	760	13.5	745	13.7	730
11.3	850	12.2	620	12.5	605	13.1	760	14.3	670	14.5	605	14.7	575
12.1	650	13.0	615	13.1	620	14.1	700	15.3	525	15.5	600	15.7	580
12.9	640	13.8	635	14.1	670	15.1	810	16.3	505	16.5	555	16.7	530
13.6	675	14.6	790	14.9	815	16.1	765			17.5	520	17.7	515
14.5	880	15.4	790	15.6	720	17.1	480						
15.2	860	16.2	730	16.5	690								
16.0	810	16.8	690	17.3	670								
16.8	780												
17.6	760												

[1]See figure 8 for thermocouple locations.

Table 4.--Temperature data obtained at 5-foot height along center of corridor during Test No. 2[1]

Thermocouple 6		Thermocouple 10		Thermocouple 21		Thermocouple 27		Thermocouple 30		Thermocouple 34		Thermocouple 36	
Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.
Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.
0	40	0	40	0	40	0	50	0	50	0	50	0	50
1.9	45	2.0	45	2.4	50	1.0	50	1.0	50	1.0	55	1.0	55
2.7	55	2.8	60	3.2	75	2.0	60	2.0	65	2.0	70	2.0	70
3.5	95	3.6	90	4.0	130	3.0	90	3.0	100	3.0	140	3.0	135
4.3	165	4.4	170	4.8	210	4.0	170	4.0	195	4.0	270	4.0	250
5.1	255	5.2	260	5.6	290	5.0	300	5.0	320	5.0	390	5.0	365
5.9	320	6.0	315	6.4	385	6.0	390	6.0	455	6.0	680	6.0	695
6.7	710	6.8	880	7.2	910	7.0	770	7.0	710	7.0	750	7.0	715
7.5	1180	7.6	1015	8.0	865	8.0	780	8.0	725	8.0	765	8.0	740
8.3	840	8.4	965	8.8	760	9.0	750	9.0	735	9.0	785	9.0	770
9.1	780	9.2	840	9.6	810	10.0	785	10.0	750	10.0	775	10.0	770
9.9	985	10.0	905	10.4	805	11.0	825	11.0	800	11.0	825	11.0	820
10.7	1125	10.8	1060	11.2	880								
11.5	970	11.6	985	12.0	1085								
12.3	730	12.4	690	12.8	605								

[1]See figure 9 for thermocouple locations.

Table 5.--Temperaturedata obtained at 5-foot height along middle of corridor during Test No. 3[1]

Thermocouple 6		Thermocouple 10		Thermocouple 21		Thermocouple 27		Thermocouple 30		Thermocouple 34		Thermocouple 36	
Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.
Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.
0	45	0	45	0	45	0	45	0	45	0	45	0	45
1.9	50	2.0	55	2.4	70	1.1	45	1.25	45	1.45	50	1.55	55
2.6	90	2.8	110	3.2	150	2.1	55	2.25	65	2.45	75	2.55	80
3.5	175	3.6	200	3.9	245	3.1	135	3.25	145	3.45	200	3.55	210
4.2	270	4.4	285	4.8	320	4.1	280	4.25	290	4.45	340	4.55	350
5.1	370	5.2	380	5.6	440	5.1	385	5.25	410	5.45	480	5.55	545
5.9	590	6.0	655	6.4	730	6.1	610	6.25	650	6.45	810	6.55	810
6.7	790	6.8	790	7.1	740	7.1	750						
7.4	780	7.6	765	7.9	760								
8.2	850	8.3	835	8.7	865								
9.0	915	9.2	1025	9.6	1010								
9.8	1060	9.9	1035	10.3	1080								
10.6	1135	10.8	1135	11.1	1165								
11.4	1465	11.5	1070	11.9	740								

[1]See figure 9 for thermocouple locations.

Table 6.--Wall temperature data obtained during Test No. 11[1]

Thermocouple 2		Thermocouple 4		Thermocouple 16		Thermocouple 18		Thermocouple 24	
Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.
Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.
				WEST WALL					
0	30	0	30	0	30	0	30	0	30
1.4	50	1.7	70	2.0	65	2.1	65	2.2	50
2.3	120	2.5	140	2.8	125	3.0	120	3.1	115
3.1	215	3.2	250	3.6	225	3.8	205	3.9	200
3.9	340	4.0	390	4.4	340	4.5	300	4.6	275
4.7	480	4.8	510	5.2	430	5.3	360	5.4	330
5.5	585	5.6	610	6.0	475	6.0	395	6.2	370
6.3	635	6.3	620	6.7	505	6.8	420	7.0	425
7.1	790	7.1	765	7.6	800	7.6	680	7.8	600
7.9	1060	8.0	870	8.4	650	8.5	580	8.7	510
8.7	875	8.8	725	9.2	580	9.2	520	9.4	505
9.5	925	9.6	820	10.0	780	10.0	655	10.2	600
10.3	1300	10.4	1050	10.8	860	10.9	710	11.0	635
11.1	1280	11.2	1100	11.6	820	11.7	685	11.9	615
12.0	1180	12.0	1060	12.4	800	12.5	670	12.7	610
12.7	1165	12.8	1075	13.2	815	13.3	690	13.5	640
13.5	1220	13.6	1140	14.0	860	14.0	860	14.3	710
14.4	1410	14.4	1340	14.8	1080	14.9	900	15.0	790
15.1	1460	15.2	1415	15.6	1100	15.7	915	15.9	775
15.9	1370	16.0	1295	16.4	1035	16.5	870	16.6	755
16.7	1295	16.8	1240	17.2	1025	17.3	850	17.4	750
17.5	1305	17.6	1255						

Thermocouple 3		Thermocouple 7		Thermocouple 11		Thermocouple 22		Thermocouple 32	
Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.
Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.
				EAST WALL					
0	30	0	30	0	30	0	30	0	42
1.6	85	1.8	70	2.7	110	2.2	80	1.4	50
2.4	160	2.6	160	3.4	190	3.0	140	2.4	80
3.2	280	3.3	270	4.3	290	3.8	220	3.4	150
4.0	470	4.1	405	5.0	365	4.6	310	5.4	290
4.7	625	4.9	510	5.8	400	5.4	360	6.4	355
5.6	675	5.7	540	6.6	435	6.2	380	7.4	375
6.3	715	6.5	570	7.4	635	7.0	425	8.4	675
7.2	1040	7.3	895	8.2	615	7.8	620	9.4	670
8.0	1150	8.1	820	9.0	535	8.6	525	10.4	560
8.8	850	8.9	640	9.8	635	9.4	485	11.4	755
9.6	975	9.8	745	10.6	755	10.3	630	12.4	745
10.4	1370	10.5	980	11.4	730	11.1	670	13.4	750
11.2	1290	11.3	915	12.3	705	11.9	640	14.4	635
12.0	1160	12.1	830	13.0	715	12.6	620	16.4	470
12.8	1190	12.9	835	13.8	770	13.4	650	17.4	470
13.6	1295	13.7	900	14.7	950	14.2	700		
14.4	1470	14.6	1150	15.4	995	15.0	790		
15.2	1510	15.3	1195	16.2	940	15.8	780		
16.0	1360	16.1	1080	17.0	920	16.6	750		
16.7	1300	16.9	1040			17.4	745		
17.5	1340								

[1]See figure 8 for thermocouple locations.

Table 7.--Wall temperature data obtained during Test No. 2[1]

Thermocouple 2		Thermocouple 4		Thermocouple 15		Thermocouple 16		Thermocouple 17		Thermocouple 18		Thermocouple 23		Thermocouple 24		Thermocouple 28	
Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.
Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.
								WEST WALL									
0	40	0	40	0	40	0	40	0	40	0	40	0	40	0	40	0	50
1.7	80	1.8	105	2.2	110	2.2	110	2.2	70	2.3	80	2.4	90	2.4	90	1.0	50
2.5	140	2.6	190	3.0	200	3.0	200	3.0	110	3.1	140	3.2	150	3.2	160	2.0	73
3.3	255	3.4	350	3.8	315	3.8	330	3.8	165	3.9	230	4.0	220	4.0	250	3.0	120
4.1	400	4.2	540	4.6	420	4.6	460	4.6	240	4.7	330	4.8	295	4.8	335	4.0	180
4.9	500	5.0	655	5.4	495	5.4	550	5.4	290	5.5	400	5.6	335	5.6	395	5.0	250
5.7	590	5.8	740	6.2	980	6.2	830	6.2	545	6.3	560	6.4	640	6.4	620	6.0	420
6.5	1050	6.6	1285	7.0	1275	7.0	1105	7.0	880	7.1	850	7.2	810	7.2	780	7.0	600
7.3	1165	7.4	1285	7.8	1130	7.8	1110	7.8	875	7.9	885	8.0	780	8.0	770	8.0	625
8.1	1275	8.2	1285	8.6	1125	8.6	1090	8.6	875	8.7	875	8.8	760	8.8	765	9.0	630
8.9	1160	9.0	1135	9.4	1135	9.4	1075	9.4	920	9.5	880	9.6	800	9.6	780	10.0	655
9.7	1120	9.8	1020	10.2	910	10.2	1000	10.2	850	10.3	860	10.4	805	10.4	775	11.0	845
10.5	1035	10.6	1040	11.0	965	11.0	1000	11.0	910	11.1	975	11.2	890	11.2	890		
11.3	915	11.4	910	11.8	820	11.8	910	11.8	805	11.9	970	12.0	960	12.0	1045		
12.1	810	12.2	780	12.6	660	12.6	775	12.6	645	12.7	835	12.8	635	12.8	790		

Thermocouple 3		Thermocouple 7		Thermocouple 8		Thermocouple 11		Thermocouple 12		Thermocouple 19		Thermocouple 22		Thermocouple 25		Thermocouple 32	
Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.
Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.
								EAST WALL									
0	40	0	40	0	40	0	40	0	40	0	40	0	40	0	50	0	50
1.8	100	1.9	100	2.0	100	2.0	85	2.1	65	2.3	105	2.4	100	1.0	50	1.0	50
2.6	170	2.7	190	2.8	190	2.8	130	2.9	100	3.1	180	3.2	180	2.0	70	2.0	74
3.4	305	3.5	365	3.6	310	3.6	230	3.7	165	3.9	270	4.0	285	3.0	115	3.0	125
4.2	450	4.3	515	4.4	420	4.4	340	4.5	240	4.7	345	4.8	375	4.0	170	4.0	200
5.0	560	5.1	620	5.2	500	5.2	430	5.3	310	5.5	390	5.6	445	5.0	230	5.0	275
5.8	645	5.9	705	6.0	625	6.0	520	6.1	410	6.3	670	6.4	675	6.0	295	6.0	475
6.6	1005	6.7	1190	6.8	1180	6.8	930	6.9	935	7.1	810	7.2	865	7.0	585	7.0	630
7.4	1085	7.5	1180	7.6	1155	7.6	1045	7.7	950	7.9	760	8.0	855	8.0	575	8.0	690
8.2	1295	8.3	1205	8.4	1140	8.4	1050	8.5	965	8.7	680	8.8	840	9.0	625	9.0	720
9.0	1270	9.1	975	9.2	1075	9.2	1020	9.3	980	9.5	745	9.6	850	10.0	620	10.0	735
9.8	1080	9.9	1000	10.0	985	10.0	955	10.1	930	10.3	720	10.4	830	11.0	730	11.0	875
10.6	975	10.7	970	10.8	1010	10.8	975	10.9	1060	11.1	855	11.2	955				
11.4	875	11.5	875	11.6	870	11.6	930	11.7	795	11.9	825	12.0	980				
12.2	790	12.3	760			12.4	730	12.5	220	12.7	215	12.8	305				

[1]See figure 9 for thermocouple locations.

Table 8.--Wall temperature data obtained during Test No. 3[1]

Thermocouple 2		Thermocouple 4		Thermocouple 15		Thermocouple 16		Thermocouple 17		Thermocouple 18		Thermocouple 23		Thermocouple 24		Thermocouple 29	
Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.
Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.
								WEST WALL									
0	45	0	45	0	45	0	45	0	45	0	45	0	45	0	45	0	45
1.8	120	1.8	145	2.2	150	2.2	130	2.3	120	2.3	150	2.4	160	2.4	140	1.15	55
2.5	210	2.5	265	3.0	260	3.0	230	3.0	210	3.1	280	3.2	270	3.3	270	2.15	115
3.3	365	3.4	455	3.7	360	3.8	360	3.8	290	3.8	415	4.0	350	4.0	360	3.15	225
4.1	515	4.2	585	4.6	480	4.6	465	4.6	365	4.7	530	4.8	455	4.9	475	4.15	335
5.0	860	5.1	990	5.4	885	5.4	730	5.5	630	5.5	730	5.7	695	5.7	675	5.15	490
5.8	1180	5.8	1190	6.2	1240	6.2	1040	6.3	940	6.3	1010	6.5	890	6.5	870	6.15	790
6.6	1350	6.6	1335	7.0	1220	7.0	1105	7.0	925	7.0	1045	7.2	930	7.2	930		
7.3	1370	7.4	1335	7.7	1310	7.7	1155	7.8	1050	7.8	1105	8.0	1000	8.0	1000		
8.1	1410	8.2	1400	8.5	1410	8.6	1235	8.6	1140	8.6	1165	8.8	1070	8.8	1060		
8.8	1460	8.9	1370	9.3	1345	9.3	1260	9.4	1200	9.4	1195	9.6	1035	9.6	1040		
9.7	1385	9.8	1360	10.1	1445	10.2	1275	10.2	1225	10.2	1200	10.4	1130	10.4	1110		
10.5	1475	10.5	1495	11.0	1550	11.0	1360	11.0	1300	11.0	1245	11.2	1225	11.2	1190		
11.3	1510	11.4	1555	11.7	1135	11.7	1140	11.8	625	11.8	780	12.0	660	12.0	835		

Thermocouple 3		Thermocouple 7		Thermocouple 8		Thermocouple 11		Thermocouple 12		Thermocouple 19		Thermocouple 22		Thermocouple 25		Thermocouple 32	
Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.
Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.
								EAST WALL									
0	45	0	45	0	45	0	45	0	45	0	45	0	45	0	45	0	45
1.8	155	1.9	180	1.9	120	2.0	95	2.1	115	2.3	110	2.4	125	1.0	45	1.35	50
2.5	270	2.7	320	2.7	215	2.8	170	2.9	195	3.1	200	3.2	220	2.0	75	2.35	70
3.3	440	3.5	515	3.5	330	3.6	285	3.6	290	3.8	265	4.0	320	3.0	140	3.35	125
4.2	585	4.3	680	4.3	415	4.4	400	4.5	380	4.7	355	4.8	430	4.0	225	4.35	225
5.0	1040	5.1	1065	5.2	770	5.3	665	5.3	610	5.5	550	5.6	605	5.0	320	5.35	345
5.8	1280	5.9	1275	5.9	1210	6.0	970	6.0	965	6.3	900	6.5	855	6.0	600	6.35	660
6.6	1440	6.7	1415	6.7	1390	6.8	1140	6.9	1070	7.1	925	7.2	920	7.0	805		
7.4	1450	7.4	1385	7.5	1335	7.6	1160	7.6	1110	7.8	1045	7.9	995				
8.1	1490	8.2	1445	8.3	1455	8.4	1260	8.4	1230	8.6	1125	8.7	1070				
8.9	1550	9.0	1455	9.1	1490	9.2	1310	9.2	1240	9.5	1155	9.6	1095				
9.7	1420	9.8	1410	9.9	1450	10.0	1325	10.0	1250	10.3	1195	10.4	1145				
10.5	1580	10.6	1570	10.7	1590	10.8	1440	10.8	1385	11.1	1270	11.2	1255				
11.3	1580	11.5	1465	11.5	1350	11.6	970	11.6	165	11.8	200	12.0	200				

[1]See figure 9 for thermocouple locations.

Table 9.--Ceiling temperature data obtained during Test No. 1[1]

Thermocouple 1		Thermocouple 5		Thermocouple 9		Thermocouple 20		Thermocouple 26		Thermocouple 29		Thermocouple 33		Thermocouple 35	
Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.
Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.
0	30	0	30	0	30	0	30	0	42	0	42	0	42	0	38
1.3	50	1.7	75	2.6	160	2.2	90	1.1	50	1.2	52	1.5	50	1.6	50
2.3	150	2.5	180	3.4	300	3.0	170	2.1	85	2.2	95	2.5	75	2.6	80
3.0	290	3.2	350	4.2	465	3.8	310	3.1	195	3.2	190	3.5	140	3.6	140
3.8	480	4.0	550	5.0	590	4.5	450	5.1	325	5.2	300	4.5	150	5.6	270
4.6	660	4.8	700	5.8	665	5.3	550	6.1	390	6.2	385	5.5	275	6.6	290
5.4	765	5.6	760	6.6	700	6.1	600	7.1	430	7.2	415	6.5	340	7.6	385
6.3	800	6.4	790	7.4	1110	7.0	650	8.1	715	8.2	700	7.5	355	8.6	675
7.0	1085	7.2	1255	8.2	980	7.7	965	9.1	675	9.2	670	8.5	675	9.6	670
7.9	1400	8.0	1190	9.0	810	8.6	810	10.1	660	10.2	630	9.5	670	10.6	535
8.7	1000	8.8	890	9.8	980	9.4	755	11.1	755	11.2	750	10.5	550	11.6	755
9.4	1050	9.7	1040	10.6	1145	10.2	905	12.1	750	12.2	750	11.5	750	12.6	750
10.3	1510	10.4	1320	11.4	1060	11.0	985	13.1	750	13.2	750	12.5	750	13.6	740
11.1	1385	11.2	1200	12.2	1000	11.8	930	14.1	705	14.2	685	13.5	745	14.6	595
11.9	1240	12.0	1110	13.0	1015	12.5	900	15.1	830	15.2	785	14.5	620	15.6	630
12.6	1240	12.8	1120	13.8	1080	13.4	930	16.1	825	16.2	790	15.5	590	16.6	610
13.4	1300	13.6	1185	14.6	1305	14.2	1010	17.1	780	17.2	765	16.5	560	17.6	600
14.2	1610	14.4	1475	15.4	1335	15.0	1160					17.5	565		
15.1	1615	15.2	1515	16.2	1190	15.8	1140								
15.8	1425	16.0	1300	17.0	1145	16.6	1055								
16.6	1330	16.8	1240			17.3	1035								
17.4	1350	17.6	1260												

[1]See figure 8 for thermocouple locations.

Table 10.--Ceilingtemperature data obtained during Test No. 2[1]

Thermocouple 1		Thermocouple 5		Thermocouple 9		Thermocouple 20		Thermocouple 26		Thermocouple 29		Thermocouple 33		Thermocouple 35	
Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.
Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.
0	40	0	40	0	40	0	40	0	50	0	50	0	50	0	50
1.7	95	1.8	100	2.0	85	2.3	80	1.0	50	1.0	55	1.0	55	1.0	58
2.5	190	2.6	200	2.8	170	3.1	150	2.0	110	2.0	110	2.0	80	2.0	85
3.3	350	3.4	375	3.6	310	3.9	265	3.0	225	3.0	235	3.0	150	3.0	155
4.1	525	4.2	560	4.4	470	4.7	405	4.0	400	4.0	400	4.0	265	4.0	275
4.9	680	5.0	710	5.2	610	5.5	515	5.0	555	5.0	540	5.0	360	5.0	380
5.7	780	5.8	800	6.0	740	6.3	770	6.0	735	6.0	800	6.0	610	6.0	665
6.5	1275	6.6	1415	6.8	1260	7.1	1115	7.0	1055	7.0	945	7.0	685	7.0	725
7.3	1390	7.4	1440	7.6	1260	7.9	1080	8.0	1020	8.0	945	8.0	720	8.0	770
8.1	1540	8.2	1415	8.4	1220	8.7	1060	9.0	980	9.0	925	9.0	750	9.0	770
8.9	1465	9.0	1280	9.2	1155	9.5	1055	10.0	950	10.0	900	10.0	750	10.0	780
9.7	1300	9.8	1200	10.0	1105	10.3	1005	11.0	1025	11.0	1020	11.0	810	11.0	860
10.5	1150	10.6	1185	10.8	1160	11.1	1110								
11.3	1000	11.4	1070	11.6	1105	11.9	1190								
12.1	875	12.2	930	12.4	970	12.7	905								

[1]See figure 9 for thermocouple locations.

Table 11.--Ceilingtemperature data obtained during Test No. 3[1]

Thermocouple 1		Thermocouple 5		Thermocouple 9		Thermocouple 20		Thermocouple 26		Thermocouple 29		Thermocouple 33		Thermocouple 35	
Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.
Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.
0	45	0	45	0	45	0	45	0	45	0	45	0	45	0	45
1.7	150	1.8	145	1.9	130	2.3	190	1.05	55	1.2	55	1.4	55	1.5	55
2.5	280	2.6	290	2.7	255	3.2	385	2.05	130	2.2	105	2.4	90	2.5	95
3.3	530	3.4	530	3.6	450	3.9	540	3.05	300	3.2	250	3.4	210	3.5	210
4.1	695	4.2	700	4.4	620	4.7	725	4.05	525	4.2	425	4.4	360	4.5	375
5.0	915	5.1	905	5.2	855	5.6	985	5.05	725	5.2	620	5.4	505	5.5	550
5.8	1255	5.9	1230	5.9	1190	6.4	1185	6.05	1075	6.2	960	6.4	750	6.5	775
6.5	1570	6.6	1530	6.8	1370	7.1	1215	7.05	1100						
7.3	1575	7.4	1500	7.5	1345	7.9	1300								
8.0	1585	8.2	1520	8.3	1425	8.7	1340								
8.8	1640	9.0	1510	9.1	1440	9.5	1280								
9.6	1555	9.8	1480	9.9	1370	10.3	1310								
10.4	1675	10.5	1650	10.7	1510	11.1	1395								
11.3	1740	11.4	1775	11.5	1280	11.9	580								

[1]See figure 9 for thermocouple locations.

Table 12.--Floortemperature data obtained during Test No. 1[1]

Thermocouple 13		Thermocouple 14		Thermocouple 31	
Time	Temp.	Time	Temp.	Time	Temp.
Min.	° F.	Min.	° F.	Min.	° F.
0	30	0	30	0	52
2.7	45	2.9	40	1.4	50
3.5	60	3.7	40	2.4	70
4.4	85	4.5	55	3.4	155
5.1	120	5.1	65	5.4	295
5.9	140	5.9	80	6.4	360
6.7	155	6.8	95	7.4	385
7.5	310	7.6	150	8.4	680
8.3	270	8.4	170	9.4	670
9.0	250	9.2	170	10.4	575
9.8	300	9.9	185	11.4	760
10.6	385	10.8	250	12.4	750
11.5	395	11.6	255	13.4	750
12.4	395	12.4	260	14.4	655
13.1	415	13.2	260	15.4	455
13.9	450	14.0	270	16.4	340
14.7	865	14.8	360	17.4	370
15.5	695	15.5	370		
16.3	635	16.3	375		
17.0	630	17.0	380		

[1]See figure 8 for thermocouple locations.

Table 13.--Floor temperature data obtained during Test No. 2[1]

Thermocouple 13		Thermocouple 14		Thermocouple 31	
Time	Temp.	Time	Temp.	Time	Temp.
Min.	° F.	Min.	° F.	Min.	° F.
0	40	0	40	0	55
2.1	45	2.1	40	1.0	55
2.9	50	2.9	45	2.0	57
3.7	60	3.7	50	3.0	60
4.5	85	4.5	60	4.0	70
5.3	115	5.3	80	5.0	85
6.1	155	6.1	100	6.0	130
6.9	740	6.9	285	7.0	270
7.7	655	7.7	300	8.0	315
8.5	510	8.5	300	9.0	310
9.3	460	9.3	305	10.0	350
10.1	540	10.1	330	11.0	390
10.9	880	10.9	375		
11.7	805	11.7	960		
		12.5	310		

[1]See figure 9 for thermocouple locations.

Table 14.--Floor temperature data obtained during Test No. 3[1]

Thermocouple 13		Thermocouple 14		Thermocouple 31	
Time	Temp.	Time	Temp.	Time	Temp.
Min.	° F.	Min.	° F.	Min.	° F.
0	45	0	45	0	45
2.1	50	2.1	45	1.3	45
2.9	60	2.9	50	2.3	50
3.7	90	3.7	65	3.3	55
4.5	125	4.5	90	4.3	75
5.3	190	5.4	120	5.3	100
6.1	390	6.1	240	6.3	400
6.9	470	6.9	310		
7.7	500	7.7	340		
8.4	600	8.5	395		
9.2	695	9.3	500		
10.0	725	10.1	505		
10.8	750	10.9	510		
11.6	780	11.7	290		

[1]See figure 9 for thermocouple locations.

Table 15.--Temperaturedata for ignition specimens (Test No. 1)[1]

Thermocouple 8		Thermocouple 15		Thermocouple 12		Thermocouple 17		Thermocouple 19		Thermocouple 23		Thermocouple 25		Thermocouple 28	
Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.	Time	Temp.
Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.	Min.	° F.
0	30	0	30	0	30	0	30	0	30	0	30	0	42	0	42
2.6	85	2.7	80	2.6	100	2.8	70	2.9	85	3.0	70	1	45	1.2	50
3.3	140	3.6	130	3.5	150	3.6	100	3.7	130	3.8	100	2	55	2.2	65
4.1	215	4.4	210	4.2	235	4.4	150	4.5	195	4.6	125	3	90	3.2	125
4.9	280	5.2	275	5.0	300	5.3	205	5.2	255	5.4	170	4	140	4.2	170
5.7	340	6.0	310	5.8	350	6.0	230	6.0	290	6.2	200	5	215	5.2	315
6.5	375	6.7	345	6.6	390	6.8	260	6.9	330	7.0	250	6	275	6.2	385
7.3	975	7.5	835	7.4	880	7.6	575	7.6	655	7.8	425	7	380	7.2	380
8.1	590	8.3	510	8.2	580	8.5	425	8.4	490	8.6	350	8	405	8.2	710
9.0	550	9.2	495	9.0	510	9.3	430	9.2	500	9.4	355	9	675	9.2	675
9.7	750	10.0	760	9.8	750	10.0	590	10.0	685	10.2	465	10	670	10.2	650
10.5	920	10.8	770	10.6	820	10.9	615	10.9	715	11.0	450	11	550	11.2	755
11.3	850	11.6	720	11.4	760	11.6	620	11.7	700	11.8	470	12	750	12.2	745
12.2	845	12.4	720	12.2	760	12.5	635	12.5	725	12.6	510	13	760	13.2	755
12.9	900	13.2	775	13.0	835	13.2	675	13.3	770	13.4	555	14	665	14.2	685
13.7	1085	14.0	880	13.9	940	14.0	740	14.1	860	14.2	670	15	595	15.2	785
14.5	1200	14.8	1135	14.6	1225	14.8	980	14.9	1020	15.0	790	16	525	16.2	540
15.3	1355	15.6	1040	15.4	1120	15.6	945	15.7	975	15.8	775	17	500	17.2	530
16.2	1140	16.4	990	16.2	1100	16.4	1135	16.4	1005	16.6	795				
16.9	1150	17.2	1050	17.0	1100	17.2	835	17.2	1020	17.4	830				

[1]See figure 8 for thermocouple locations.