NATIONAL BUREAU OF STANDARDS REPORT

9455

FIRE PERFORMANCE CHARACTERISTICS OF EXTERIOR WALLS

by

D. Gross

to

Federal Housing Administration
U. S. Department of Housing and Urban Development
Washington. D. C.

NBS

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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ABSTRACT

Test results are presented of surface flammability, smoke accumulation, and the penetration of flame on both surfaces of typical sections of selected exterior wall assemblies. The test methods used are described, and properties are suggested which could serve as performance criteria for fire hazard evaluation of exterior walls.

1. Introduction

The overall objectives of this project are to adapt or develop test methods and techniques for the measurement of the performance of exterior walls, and to determine these properties for a selected group of representative walls. From the standpoint of fire, the objectives were to consider those characteristics of exterior walls which are of importance to life safety, and to compare the performance of walls of various types as a means for assisting the sponsor in establishing levels of acceptability.

One and two-family residences have traditionally been considered less of a fire problem compared to apartments or office buildings, principally because rapid escape by a relatively small number of occupants is generally possible. Thus the provisions of the NFPA Building Exits Code pertaining to interior finishes in one and two-family dwellings are seldom applied or enforced. Nevertheless, nearly one-half the fire deaths (which number approximately 12,000 annually) occur in one and two-family dwellings, and, of the more than 500,000 fires in such dwellings annually, there are nearly 200 multiple-death fires [1].

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Fire authorities consider asphyxiation due to the toxic decomposition products in smoke to be the most serious source of fire fatalities. This is followed, in order, by rapidly-developing fires which cause panic and prevent rescue or escape, and by combustible interior finish which contributes to the rapidity of fire spread. While it is acknowledged that interior finishes in residences are not the only or major fire hazard, it is clearly recognized as a known contributor to fire deaths, and one which can be controlled.

Of the characteristics of walls which are directly related to life safety, the following should be considered most important:

Toxic products of combustion
Smoke (visual obscuration)
Surface flammability
Flame penetration
Heat of combustion

While it is not possible to relate any of these characteristics directly and quantitatively to a life hazard under all use conditions, comparative test methods now exist or can be developed or adapted for the measurement of all of the characteristics listed except the first one. Considerably more laboratory work seems to be necessary before the measurement of the type and quantity of toxic combustion products can be determined with ease and precision.

It should be noted that, from the standpoint of fire safety, it is primarily the interior surfaces of a dwelling which are important, whether these be part of exterior wall assemblies, or of partitions, ceilings, floors or doors. However, in some cases, the fire properties of the outside surfaces of exterior walls, for example smoke production, rapidity of flame spread, the ease of flame penetration, and internal fire propagation, may also be important.

In this study, measurements were made of surface flammability, smoke accumulation, and the penetration of flame on both interior and exterior surfaces of selected exterior wall assemblies. Time and monetary limitations did not permit the measurement of toxic combustion products or of the heat of combustion. Studies to evaluate the spread of fire externally through windows, to adjacent structures by firebrands or radiation, or internally within the wall structure core, were also beyond the scope of this investigation.

2. Test Methods

2.1 Surface Flammability

These measurements were made using the radiant panel flame-spread test apparatus (see Fig. 1). The detailed test procedure is outlined elsewhere [2, 3]. In brief, the test requires a 6 by 18 in. specimen, facing and inclined 30 degrees to a vertically-mounted, gas-fired radiant panel. The energy output of the panel was controlled to be the same as that from a blackbody of the same dimensions operating at a temperature of 670°C (1238°F). Ignition was initiated at the upper edge of the test specimen and observations were made of the progress of the flame front down the specimen surface, as well as the temperature rise of the thermocouples in a stack supported above the test specimen. The test duration was 15 min., or until sustained flame propagated down the entire 18 in. length of specimen, whichever time was less. The flame-spread index, I_s,

was computed as the product of the flamespread factor F_s and the heat evolution Q, or $I_s = F_s Q$, where

$$F_s = 1 + \frac{1}{t_3} + \frac{1}{t_6-t_3} + \frac{1}{t_9-t_6} + \frac{1}{t_{12}-t_9} + \frac{1}{t_{15}-t_{12}} .$$

The symbols t_3 to t_{15} correspond to times in minutes from specimen exposure until arrival of the flame front at a position 3 to 15 in., respectively, along the length of the specimen. The heat evolution Q is proportional to the observed maximum temperature rise of the stack thermocouples.

All specimens were conditioned by pre-drying at 140°F and then permitted to reach equilibrium with an ambient maintained at 73±5°F and 50±5 percent relative humidity.

2.2 Smoke Accumulation

The smoke produced during the burning of the test specimens was collected and measured photometrically, employing a laboratory test method developed for the purpose [4]. As shown in Fig. 2, the test utilizes a closed chamber of 18 cu. ft. volume containing an electrically-heated furnace which provides an irradianace of 2.5 w per sq cm (2.2 Btu/sec sq ft) on the surface of a nominal 3-in. square specimen. The method assumes the applicability of Bouguer's law to the attenuation of light by smoke, and smoke quantity is therefore reported in terms of optical density rather than light absorptance. Optical density is the single measurement most characteristic of a "quantity of smoke" with regard to visual obscuration. To take into account the optical path length L, the volume of the chamber V, and the specimen surface area producing smoke A, a specific optical density is defined as $D_s = V/LA\ (\log_{10} 100/T)$, where T is the percent light transmittance. Thus, for a selected exposure in the test chamber, and within certain limitations, a single test permits rough extrapolation to surface areas and to chamber volumes of other size.

2.3 Flame Penetration

Each test specimen measuring 36 in. square was subjected to heat and flame impingement from a vertically oriented gas burner centrally located below the horizontally-mounted specimen (see Fig. 3). The test apparatus is fully described in Paragraph 4.3.3 "Flame-resistance tests" of Federal Specification SS-A-118 b, "Acoustical Units, Prefabricated." The flame was controlled to duplicate the prescribed time-temperature exposure in standard fire endurance tests [5] (1000°F at 5 min., 1300°F at 10 min., 1550°F at 30 min.), as indicated by a thermocouple located 1 in. below the lower surface of the specimen. The available equipment was utilized as a convenient and economical means for evaluating resistance to flame penetration from a fairly severe but localized flame. It is not to be considered as equivalent or comparable to the standard fire endurance test in which the exposing fire is applied to an entire wall surface measuring not less than 100 sq ft in area.

Thermocouples were placed at several locations within the wall structure and on the unexposed upper surface to indicate the progressive temperature increase. The unexposed surface thermocouple was placed centrally and covered with an asbestos pad conforming to the specifications prescribed in the standard fire endurance test [5]. Visual observations were also made such as the time of occurrence and extent of flaming in the core.

Separate tests were made on the exterior and interior surfaces of each wall. In addition, alternate specimens were arranged so that where possible the effects of flame impingement on an exterior joint could be compared to that of the unjointed wall section, and the heat penetration between studs could be compared to that through the studs.

3. Test Results

3.1 Surface Flammability

Individual and average flame spread index values are listed in Table 1.

The average flame spread index values ranged from 0 to 155 for the exterior wall surfaces. Flames spread to approximately 13 in. on the painted wood siding, avg $I_s = 49$, and along the full 18 in. length on the unpainted cedar plywood, avg $I_s = 155$. The latter value, which is typical for uncoated plywood, would be reduced significantly by the application of an adequate coating of a conventional paint, such as of the alkyd or latex types [6]. The stressed skin plywood sandwich panel with oil-base exterior paint had an average flame spread index of 107. Flames did not propagate along the aluminum lap siding or aluminum sandwich panel surfaces, for which the flame spread index values were zero.

For the interior wall surfaces, the average flame spread index values ranged from 0 to 105. There was only a slow, limited spread of flame along the painted gypsum board ($I_s = 8$), which formed the interior surface of three wall systems. Flames propagated to 15 in. on the plywood sandwich panel, which received two coats of latex base paint, and the average flame spread index was 105.

It was also found that the reverse or cavity sides of two exterior wall layers propagated flames more rapidly when tested as exposed surfaces. The measured flame spread index value for the fiberboard sheathing was 242 and that of the building paper/polyurethane foam/aluminum lap siding combination was 568. The possible rapid flame propagation within the core or cavity of a wall system needs to be considered, especially when the surface layers can be quickly melted or burned through from a severe localized flame source.

3.2 Smoke Accumulation

Smoke accumulation tests were performed under both flaming and non-flaming (smoldering) conditions and the results are presented in Table 2, in terms of three measured values:

(1) total maximum smoke accumulation, D_m
(2) maximum rate of smoke accumulation over a 2 min. period, R_m
(3) the time period to reach a "critical" specific optical density of 16 under the test condition.

If it is assumed that a surface area of 10 sq ft is producing smoke which distributes itself uniformly within a closed room of 2000 cu ft volume, and that a light transmittance of 16 percent over a viewing distance of 10 feet would represent a critical obscuration of vision, then this smoke level would correspond to a specific optical density of 16. Provided the generation, agglomeration and other characteristics of the smoke are similar, then the laboratory chamber may be used to measure the time period to reach this "critical" specific optical density under the given test conditions.

From Table 2, it can be seen that, under flaming exposure, smoke from the painted wood drop siding attained a maximum specific optical density level, D_m= 130, higher than from any of the other exterior surfaces tested. The unpainted cedar plywood only developed a maximum smoke level of D_m = 94, but produced smoke more rapidly than any of the other surfaces. The aluminum lap siding developed the lowest maximum smoke, D_m = 36, and at the lowest rate of all the exterior surfaces.

Under non-flaming exposure, relatively high maximum smoke levels were noted for the painted wood drop siding, D_m = 387, the unpainted cedar plywood, D_m = 366, and the painted plywood, D_m = 309. These values are comparable to those previously measured for typical cellulosic materials (fiberboard, plywood, hardboard, red oak), and illustrates that the smoke produced from smoldering cellulosic materials far exceeds that produced when these same materials are actively flaming. The painted aluminum surfaces, on the other hand, produced less smoke under the non-flaming exposure.

Of the interior wall surfaces, the painted gypsum board developed low smoke accumulation levels under both flaming (D_m = 15) and non-flaming D_m = 32) exposures. This board was used as the interior surface of three wall systems. The interior painted plywood surface of the stressed skin sandwich panel produced smoke accumulation levels similar to those obtained for the exterior plywood surfaces.

Smoke accumulation tests were also performed on the reverse surfaces of the exterior and interior layer materials where these formed the interior surfaces of the cavity. Of these surfaces, there was no smoke accumulation (D_m = 0) for the aluminum foil surfaced gypsum board under either flaming or non-flaming exposure, a moderate amount for the building paper/polyurethane foam assembly beneath the aluminum lap siding, and a considerable amount from the fiberboard sheathing beneath the wood drop siding. The latter material reached higher smoke accumulation levels for both flaming (D_m = 180) and non-flaming (D_m = 514) exposures than any other surface tested, exterior, interior or cavity.

3.3 Flame Penetration

Test results are presented in Table 3, in terms of three measured events which may be considered "critical" in terms of heat and flame penetration:

(1) flamethrough of the exposed surface or layer,
(2) a 250 deg F temperature rise in the core or stud space,
(3) a 250 deg F temperature rise on the unexposed surface.

The results indicate that a 250 deg F temperature rise usually occurs in the core or stud space prior to actual flamethrough of the exposed surface layer. With flame exposure on the exterior surface, the times to this critical temperature rise in the core or stud space ranged from about 6 min. for the aluminum sandwich wall to about 26 min. for the wood drop siding. The time for actual flamethrough varied from 10 min. for the fir plywood to 26 min. for the wood drop siding.

With flame exposure on the interior surface, the gypsum wallboard served to limit the time for the critical temperature rise in the stud space to the range of 22 to 28 min. and the time for flamethrough ranged between 26 and 38 min. Flamethrough occurred at about 9 min. for the plywood sandwich panel and at 15 min. for the aluminum sandwich panel.

The time to reach a 250 deg F temperature rise on the unexposed surface always occurred later than flamethrough of the exposed surface of the wall assembly, and ranged from as low as 10 to 14 min. for the plywood sandwich panel to approximately 36 min. for the wood drop siding wall with exterior surface fire-exposed, and 65 min. for the same wall with the interior surface exposed. This temperature rise was reached in only 8 min. at the vinyl plastic joint of aluminum sandwich wall.

A comparison of the results for between-stud versus through-stud fire exposure on the wood drop siding wall indicates no significantly different behavior. It was noted, however, that the vinyl plastic joint of the aluminum sandwich wall appeared to offer appreciably less resistance to flame penetration than the unjointed section.

Fig. 4 shows several of the representative wall assemblies after tests in which flame exposure was applied to the exterior wall surface.

4. Discussion

With respect to interior lining surfaces, there is clear and ample evidence that surface flame propagation is a characteristic which contributes directly to fire hazard. This is probably not true to the same extent for the exterior surfaces of exterior walls.

The radiant panel test method has been used for characterizing the flame spread properties of all types of materials over the past ten years. Although the scope of the ASTM version [3] only recommends it for research and development work, it appears to be suited for performance evaluation of walls. Other flame-spread test methods are also available for comparative flame-spread measurements, such as the 25-ft "tunnel" test [7] and the 8-ft "tunnel" test [8]. On the basis of flame-spread index values previously measured and reported [9, 10], as well as those measured for the representative walls included in this study, it should be possible to establish levels of performance against which to judge walls of various types. It seems reasonable to establish flame-spread index limits for the interior wall surface, the exterior wall surface, and the reverse side of the interior and exterior layers where not fastened directly to a noncombustible backing. However, the choice of acceptable limits remains arbitrary until such time as the functional relationship between flame spread index and fire hazard is known more definitely.

The production of smoke from the surface of material undergoing decomposition in the presence of a fire is most conveniently gaged by its accumulation within a closed chamber. Because of the complexity of the problem, only the visual obscuration characteristic of the smoke was considered here, and no consideration was given to the type and quantity of toxic combustion products, to the irritating and harmful effects of inhaling hot smoke particles, or to human psychological reactions leading to hysteria, etc.

Of several meaningful measures of smoke production (in terms of optical density), the following three were considered most appropriate: total smoke accumulation, maximum rate of accumulation, and time to reach a "critical" accumulation level. In actual rooms, not enough is known about how smoke accumulates and moves in response to natural and forced ventilation with typical door and window openings, for these values to be considered absolute except for closed compartments under identical conditions. For all other conditions, and particularly when considering exterior surfaces normally exposed to an unlimited atmospheric volume, the test values are only useful as comparative measures of smoke production. Data on a wide variety of typical materials used as interior finishes have been compiled in ref. [4], for both flaming and smoldering exposures.

On the basis of smoke accumulation values previously measured and reported, as well as those measured for the representative walls included in this study, it seems reasonable that maximum smoke accumulation levels can be established for the interior wall surface, the exterior wall surface, and the reverse side of the interior and exterior layers where not fastened directly to noncombustible backing. Although the interior wall surface is the most critical one, the establishment of higher levels for the other surfaces would serve to exclude the very heavy smoke-producing materials. Maximum smoke accumulation levels should be based on the higher value obtained from the flaming or the nonflaming (smoldering) test exposures. As with flame-spread index values, such levels must be set arbitrarily, rather than in terms of verified life hazard relationships.

The ability of an exterior wall structure to resist flame penetration has probably not been too great a factor in life safety in the past. Nevertheless, this factor must be considered in fire performance evaluation of walls. The method described employs simple test equipment for providing a severe, localized flame exposure. The specimen is mounted horizontally, rather than vertically. The occurrence of flame and heat penetration may be readily determined by visual observation and by means of thermal indicators, such as thermocouples.

The time to flamethrough is a measure of the wall's resistance to fire penetration, which could lead to subsequent flame propagation vertically in the stud space or core. The time to a 250 degree F temperature rise on the unexposed surface is a measure of the wall's ability to insulate against the transmission of heat which could ignite combustible material placed against the surface away from the fire. This is meaningful primarily in terms of an external fire. Both types of measurements were found to be reasonably reproducible in duplicate tests.

On the basis of the flame and heat penetration times measured for the representative walls included in this study, it seems reasonable that limiting flamethrough times can be established for both the exterior and interior wall surfaces, and a limiting temperature rise time can be established for exposure of the exterior wall surface. In addition to the typical section of the wall assembly, joints, seams or other details of questionable fire resistance, should be tested separately and in a manner likely to produce the poorest performance.

Although not included in the test result tabulations,common face brick would be rated as zero for both flame spread index and maximum smoke accumulation, and would also provide the highest resistance to flame penetration.

SUMMARY

Measurements were made of surface flammability, smoke accumulation, and the penetration of flame on both surfaces of typical sections of selected exterior wall assemblies. Consideration was also given to joints and seams, and to the reverse sides of interior and exterior layers which might become exposed to flame in the event of flamethrough of the layer. Use was made of available test methods and equipment for the flame spread and flame penetration studies, while smoke accumulation was evaluated using a test method developed for the purpose.

The following table suggests properties which could serve as performance criteria for the evaluation of exterior walls:

	Property			
Surface Exposed	Flame Spread Index	Maximum Smoke Accumulation	Time to Flamethrough Exposed Layer	Time to 250 deg F Temp Rise
Interior wall surface	x	x	x	
Exterior wall surface	x	x	x	x
Reverse (cavity) side of interior layer where not fastened directly to noncombustible backing	x	x		
Reverse (cavity) side of exterior layer where not fastened directly to noncombustible backing	x	x		
Exterior joint or seam	x	x	x	x

In the absence of verified functional relationships between laboratory test values and actual fire hazard, acceptable performance levels must be set arbitrarily.

REFERENCES

[1] "Multiple Death Fires of 1963", NFPA Quarterly, 57, p. 332, 1964.

[2] Interim Federal Standard 00136 b (COM-NBS), Dec. 26, 1962.

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[4] Gross, D., Loftus, J.J., and Robertson, A.F., "A Method for Measuring Smoke from Burning Materials", ASTM Paper No. 200, presented at ASTM Annual Meeting, June 1966.

[5] "Standard Methods of Fire Tests of Building Construction and Materials", ASTM Designation E 119-61, 1961.

[6] Gross, D., and Loftus, J.J., "Surface Flammability of Fire Retardant and Conventional Paint Assemblies", Fire Research Abstracts and Reviews, 3, 151-8, 1961.

[7] Robertson, A.F., Gross, D., and Loftus, J.J., "A Method for Measuring Surface Flammability of Materials Using a Radiant Energy Source", ASTM Proc. 56, 1437-53, 1956.

[8] Gross, D. and Loftus, J.J. "Flame Spread Properties of Building Finish Materials", ASTM Bulletin No. 230, 56-60, May 1958.

[9] "Standard Method of Test for Surface Burning Characteristics of Building Materials", ASTM Designation E 84-61, 1961.

[10] "Method of Test for Surface Flammability of Building Materials Using an 8-Foot Tunnel Furnace", ASTM Designation E 286-65 T, 1965.

TABLE 1 -- Flame Spread Index Values for Representative Walls

Wall Number		Type	Flame Spread Index I_s
1	Wood drop siding, painted	Exterior	49
2	Aluminum lap siding	Exterior	0
3	Aluminum sandwich wall	Exterior and Interior	0
4	Cedar plywood, unpainted	Exterior	155
5	Plywood, painted	Exterior	107
1,2	Gypsum board, painted	Interior	8
5	Plywood, painted	Interior	105
1	Fiberboard sheathing	Exterior Reverse (Cavity)	242
1,2	Gypsum board, unpainted	Interior Reverse (Cavity)	13
2	Building paper/polyurethane foam/aluminum lap siding	Exterior Reverse (Cavity)	568*
4	Gypsum board, aluminum foil surface	Interior Reverse (Cavity)	0*

* Average of two tests; all others average of four tests.

TABLE 2. Smoke Accumulation Test Results for Representative Walls

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Average of two tests

	Wall Number	Wall Surface	Flaming Exposure			Nonflaming Exposure		
			Max. Smoke Dm	Max. Rate Rm.	Time to $D_s = 16$	Max. Smoke Dm	Max. Rate Rm.	Time to $D_s = 16$
				min^{-1}	min		min^{-1}	min
Exterior	1	Wood drop siding, painted	130	4.4	8.4	387	16.5	3.2
Wall	2	Aluminum lap siding	36	2.9	8.2	18	1.6	18.5
	3	Aluminum sandwich wall	53	8.3	4.3	24	1.6	18.4
Surfaces	4	Cedar plywood, unpainted	94	15.5	3.8	366	42.	4.0
	5	Plywood, painted, exterior	76	7.0	5.2	309	41.3	3.0
Interior Wall	1,2	Gypsum board, painted	15	2.4	NR	32	6.0	5.2
Surfaces	5	Plywood, painted, interior	86	4.7	6.3	342	48.1	3.7
Reverse	1	Fiberboard sheathing	180	26.4	4.6	514	104.	1.4
(Cavity)	1,2	Gypsum board, unpainted	10	0.4	NR	56	10.6	4.8
	2	Building paper/polyurethane foam/sluminum lap siding	90	15.2	1.4	100	29.0	0.7
Surfaces	4	Gypsum board, aluminum foil surface	0	0	NR	0	0	NR

NR = not reached

TABLE 3. Flame Penetration Test Results for Representative Walls

Wall Number	Wall System	Surface Tested	Construction at Center of Specimen	Time, minutes: Test Duration	Time, minutes: Flamethrough Exposed Surface	Time, minutes: 250 deg F Temp. Rise Core or Stud Space	Time, minutes: 250 deg F Temp. Rise Unexposed Surface
1	Wood drop siding, Fiberboard sheathing, Wood studs, Gypsum wallboard, glass fiber - reinforced	Exterior	Between studs	38	26	26	36
			Stud	38	25	28	36
		Interior	Between studs	66	34	25	64
			Stud	68	38	24	67
2	Aluminum lap siding, Polyurethane foam, Building paper, Wood studs, Gypsum wallboard	Exterior	Stud	40	32	13	38
			Stud	20	14	13	a
		Interior	Between studs	40	34	26	38
			Between studs	35	26	22	32
3	Aluminum sandwich wall, Paper honeycomb	Both Surfaces Identical		18	14	5	16
				18	16	8	16
			Joint	10	no flame	7	8
4	Cedar plywood, unpainted, Steel studs, Mineral wool batt insulation, Gypsum wallboard aluminum - foil surfaced	Exterior	Between studs	28	10	a	26
			Between studs	24	10	11	22
		Interior	Between studs	30	27	24	29
			Between studs	36	31	28	34
5	Fir plywood, painted, Polystyrene foam, Fir plywood, painted	Exterior	Between rails	15	11	8	14
			Between rails	14	11	7	13
		Interior	Between rails	11	8	6	10
			Between rails	13	10	a	a

a Not recorded

#2 #7 #4 #6 #5

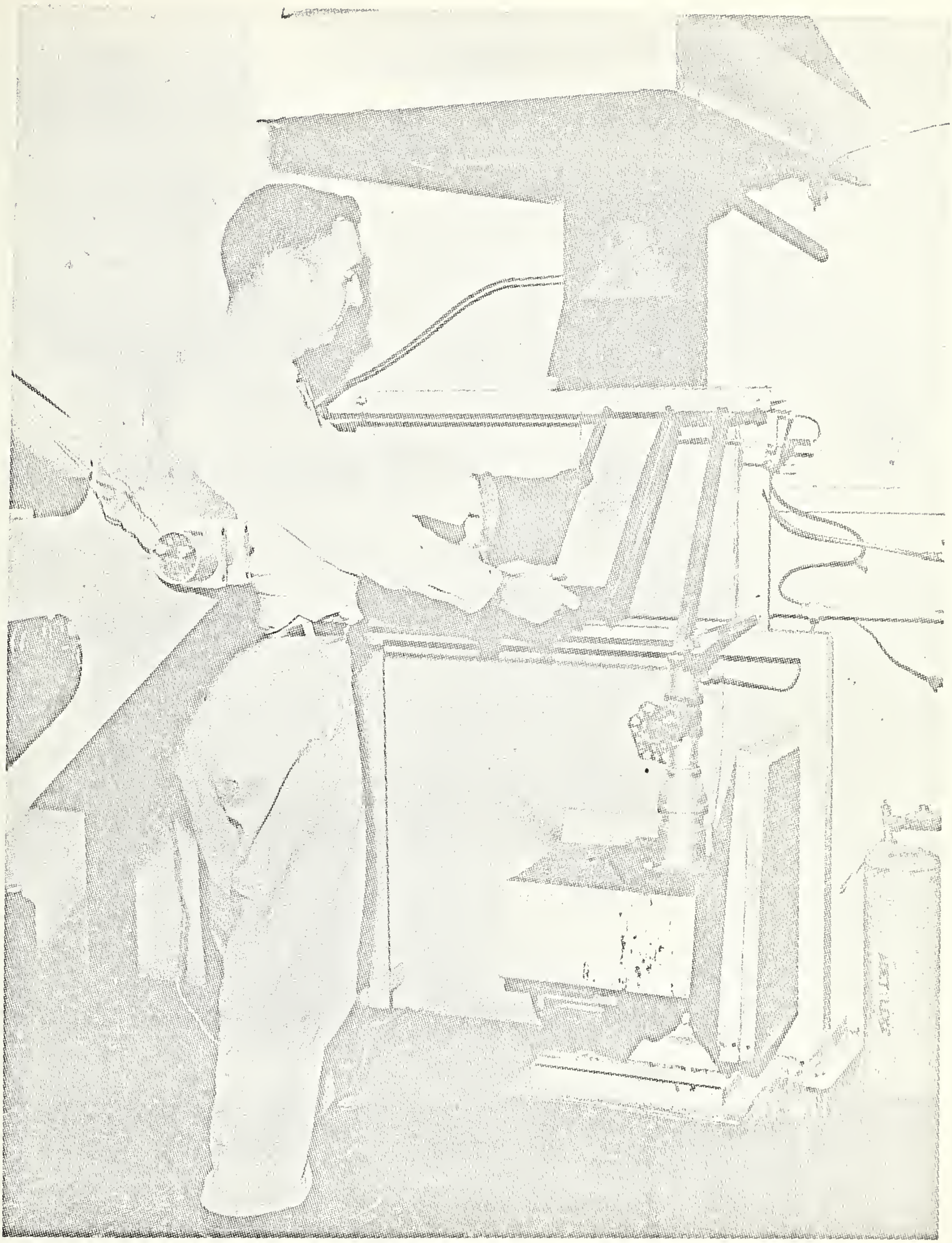

Fig. 1. Radiant Panel Flame-Spread Test Apparatus

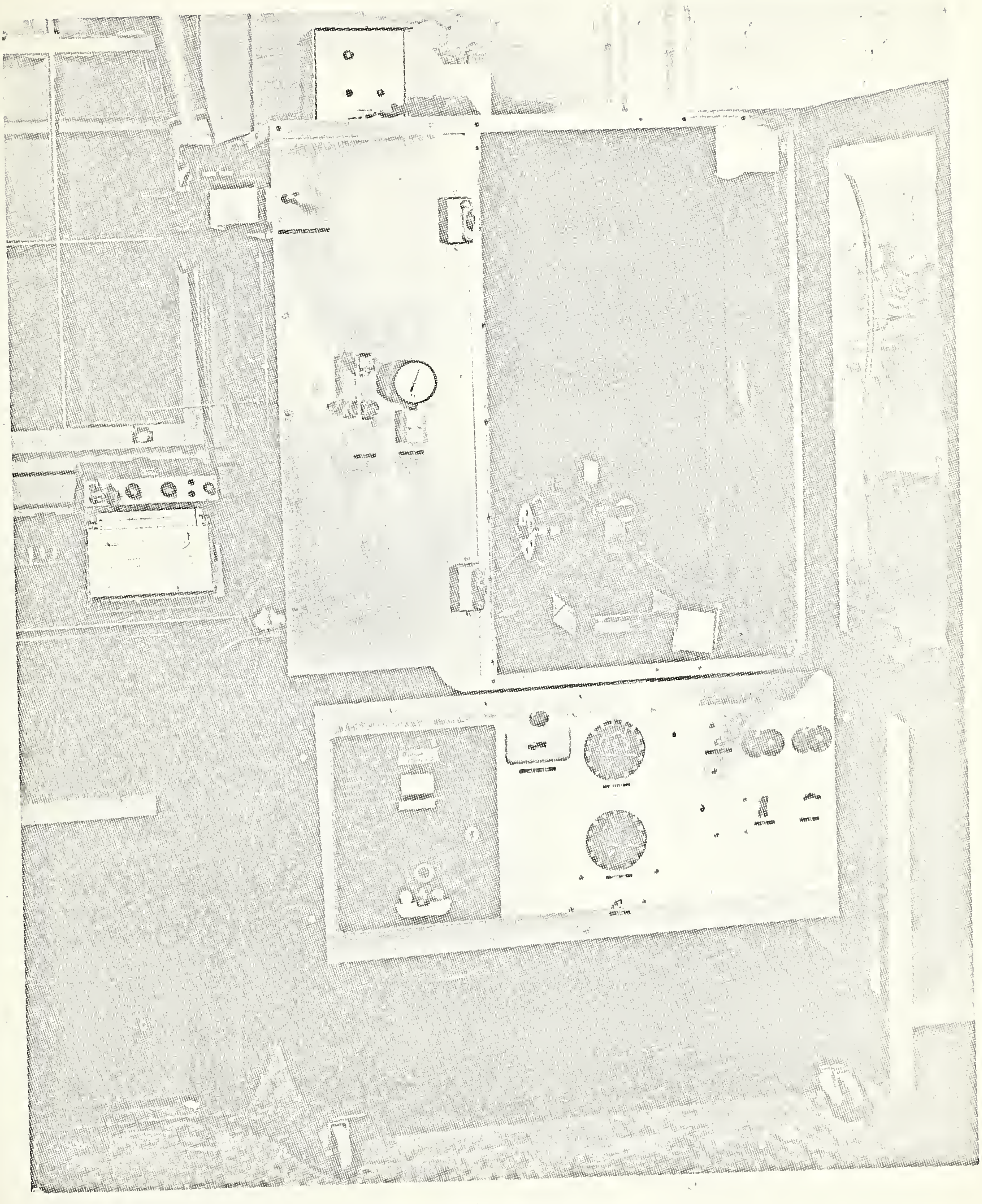

Fig. 2. Smoke Test Chamber

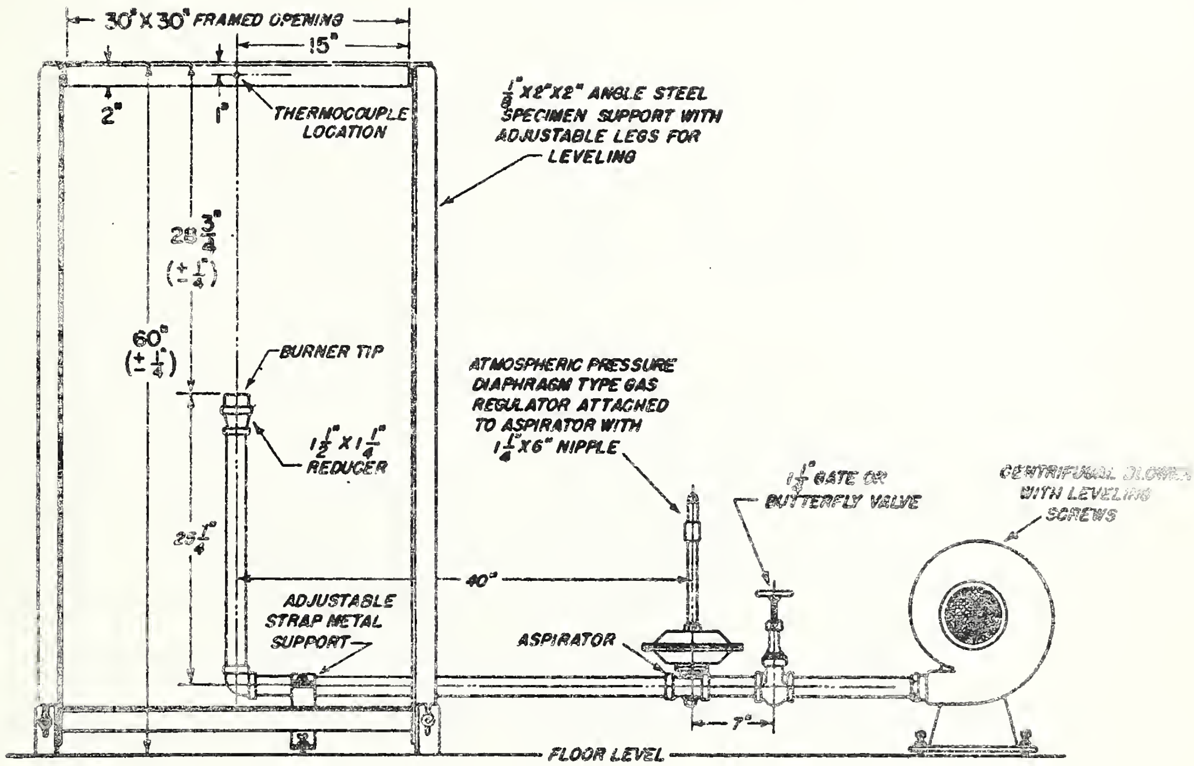

Fig. 3. Apparatus for Flame Penetration Tests

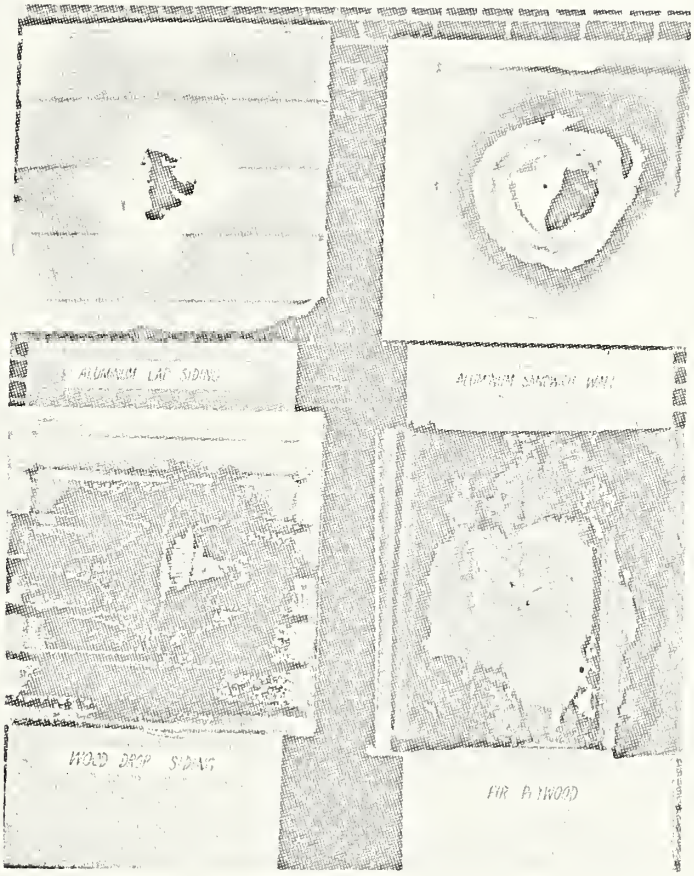

Fig. 4. Representative Wall Assemblies after Flame Penetration Test. Exterior Surface Flame Exposure

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