NATIONAL BUREAU OF STANDARDS REPORT

8172

RADIANT IGNITION OF
WALL FINISH MATERIALS IN A SMALL HOME

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U. S. DEPARTMENT OF COMMERCE
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ABSTRACT

Small-scale panels of different building finish materials were exposed to a radiant heat source to simulate the effect an overheated stove or chimney may have on interior wall or ceiling surfaces. Included in the tests were smoke measurements, and a determination of temperatures on the panel surfaces and at points in the room. Some measurements were made of CO production, and the presence of ignitable gases was checked. Tests were also made with small masses of an insulating material and with carbonized wood. Dense smoke was produced in nearly all of the tests, and there was indication that untenable conditions would be quickly achieved in a living space even without ignition of the surface finish material to active flaming.

1. Introduction

In connection with a general program of investigating several aspects of the behavior of building materials in fires, tests were made to explore the ignition properties of certain wall surface and finish materials when exposed to a radiant heat source, such as might be furnished by an overheated stove or chimney, or by the spreading heat of an accidental fire.

The tests were preliminary in nature, and severely limited in scope by the short-term availability of the test structure. Nevertheless, it was possible to conduct 14 tests of wall finish materials, in which in addition to visual observation of smoke and flaming, some smoke measurements were made, and temperatures on the front and back of test specimens and at several points in the room were determined. An effort was made to secure measurements of carbon monoxide concentration, and to determine, generally, if gases in quantity to present a flash fire or explosion hazard, or conversely, an inhibiting effect on combustion, could be produced from building materials subjected to radiant heat. As part of the investigation of the character of gas production, tests were also made with stacks of fiberboard, representing masses of insulating material, and with charcoal.

2. Description of Test Materials

A description of the specimens used in the tests is given in Table 1. Flame spread measurements, determined by the radiant panel method [1][1/] are included for a comparison of the performance of the materials under the two methods of test.

Each of the 14 test specimens subjected to radiant heat was in the form of a panel, 3 ft square. Where required, the materials were supported by a rigid backing.

The charcoal briquettes of Test 15 were a standard commercial product. Approximately 12-1/2 lb were used in the trial. In Test 16 the wood fiber board, in 1/2-in. thick sheets, was arranged in a 1-ft cube. Also in this test, four stacks of fiberboard, each with four 1-ft sq sheets, were used.

3. Test Method and Equipment

The tests were conducted in a small house (Fig. 1) on a rural site. The brick veneer structure had a living space consisting of four rooms on a single level, and an unfinished attic and basement, the latter serving as the location of the several pieces of test equipment used in the trials. The No. 2 bedroom, shown on the floor plan of Fig. 2, was used as the test area. This room, approximately 10 by 10-1/2 ft, 8 ft high, had north and east exposures, each with a 3 by 5 ft double hung wooden window. Weather tightness of the windows was aided by the use of metal weather stripping, and further by wooden storm sash fitted to the window frames. As its door was kept closed during the tests, the closet shown on the plan did not add directly to the volume of the room. Access to the room was through a hallway door, opening inward.

In conducting the tests, the 3- by 3-ft panels were mounted near the outside corner on the east wall of the test room. Four of the panels were placed against 1-5/8 in. thick furring strips laid vertically against the plaster surface. In an effort to minimize damage to the structure, the remaining specimens, mostly in the later tests, were affixed by screws directly to 4- by 7-ft sheets (two 1/2-in thicknesses) of asbestos millboard applied over 1-1/2 in. furring strips. The two methods of attaching the panels are illustrated in Fig. 3, with Table 1 indicating the method applicable in each test.

1/ Numbers in brackets refer to the list of references at the end of this report.

An assembly of four electric oven-heating elements placed in front of a 30- by 27-in. aluminum reflector served as the source of radiant heat to which the specimens were subjected. This assembly, shown in Fig. 4, was movable, and was so positioned as to be centered in front of and parallel to the test panel. All of the tests were conducted with the heater at a distance of 6 in. from the face of the specimen. By means of a timing circuit, the heater could be operated at a full or fractional duty cycle, which for many of the tests of the series was approximately 50 percent with on and off cycles of 5 sec. each. Excepting a trial in which the cycle was changed in the course of a run, the remaining tests were made with continuous power to the heater.

Power consumption for the 50 percent cycle was 6.2 kw, and for 100 percent duty 11.6 kw. On the basis of an available measured radiant intensity at a point 24 in. normal to the center of the heater, the effective blackbody temperatures were found to be 273°C (523°F) for the 50 percent duty cycle and 402°C (756°F) for the 100 percent cycle. The radiant intensities at other points on a line parallel to the heater surface and at 6 in. distance from it were calculated, as shown in Fig. 5, using a geometric configuration factor [2]. The validity of this calculated curve is indicated by the close correspondence of a curve similarly calculated for the parallel traverse 18 in. from the heater with one based on available experimental data taken with a calibrated radiometer at that distance. These curves are also shown in Fig. 5. The minor variation occurring in the two curves at 18 in. may possibly result from a slight difference in the geometry of the heater used from that of the symmetrical and uniform source assumed for the calculated values.

In tests 11 through 14, an effort was made to determine the effect of a shield placed between the specimen and heater. A 16 ga steel plate was mounted 1/2 in. in front of the exposed face of the specimen. The spacing was maintained by asbestos millboard strips at the bottom and sides of the plate, the top being left open for convection from the heated surface. The 1/2-in. separation of the specimen and shield was adopted as the result of some studies which indicated that use of greater separations did not add materially to the reduction of temperature on the face of the specimen [3]. In these tests, as in the others, the distance from the heater to the near side of the test panel was kept at 6 in.

Temperatures on the exposed and unexposed faces of a specimen, as well as at various points and levels in the test area were determined with thermocouples whose response was recorded by a 12-point or a continuous plotting electronic potentiometer.

In some of the tests, smoke measurements were made with a meter operating on the response of a photoelectric cell with type S-4 spectral characteristics, to the obscuring effect of combustion products on a light beam from a source 4 ft distant. The device is illustrated in Fig. 6. A check of the output of the photometer showed its response to be linear within 1 percent. In use, the meter was hung vertically with the window of the light source about 12 in. below the center of the ceiling. Thus, an integrated measure of transmission throughout a large portion of the room height was achieved.

Carbon monoxide determinations were made in several of the tests. For this purpose an MSA meter having a range of 0.005 to 0.15 percent CO was used. Pickup tubes for the meter were at three locations in the room, with samples drawn by a vacuum pump.

As a further check of the possibility of combustible gases being present in the distillation products of the heated test panels, an ignition system consisting of a pair of electrodes with 3/4-in. spacing was installed at a point 3 in. below the center of the ceiling. The ignitor was energized at 10-min intervals during the test, through a high voltage transformer. To determine the presence of a large volume of carbon dioxide in the distillation products, or if the available oxygen was otherwise depleted, a small lamp burning alcohol or kerosene was placed near the center of the room at a height of 52 in. above the floor. Extinction of this lamp would be an indication that the atmosphere of the room would not support combustion. As visual observation of the lamp was not always possible, a thermocouple was placed a short distance above the flame.

In Test 15, charcoal was placed in a 30-gal metal container on 1/4-in hardware cloth mounted 2 in. above the bottom. Air was introduced into the space beneath the charcoal through a 1/4-in. tube. Ignition of the charcoal was secured by a resistance wire heater passing through the center of the mass. A similar arrangement was used in Test 16, where a 1-ft cube of stacked wood fiberboard was used, except that there was no forced draft in the container. In this test also, ignition was attempted at the center of the cube of insulating board. In addition, a pile of wood fiberboard 1 ft sq and 2 in. thick was placed on top of each of four 660 watt electric hot plates. These small heaters were operated on the high setting. In a similar test with an asbestos pad over the heating element, a thermocouple placed between the pad and heater indicated a temperature of 600°C at 70 min, and a maximum of 635°C at approximately 2 hr. A somewhat faster rise may be expected with fiberboard from the contribution of its combustible content.

The period in which the tests were conducted was marked by rather severe winter weather. Minimum temperatures were below freezing on nearly all test days, and there was a varying accumulation of snow, up to 18 in. at the midpoint of the tests. The test house was located on an exposed site with no hindrance to the almost continuous wind, which at a nearby weather station measured up to approximately 25 mph.

Despite the weather, however, the temperature within the house was maintained in the range of 60 to 75°F at all times. Forced hot air heat was supplied to the test room except during times of actual test when the ducts were sealed shut to prevent dispersion of smoke through the entire structure. At such times, the door to the room was also closed, and further sealed by wadding at the bottom. The outside doors of the house were kept closed during the tests, except that in a few instances, it was necessary that they be opened in the latter part of a test to provide ventilation.

In all of the tests, visual observations to the extent allowed by the smoke in the room and condensation on the glass, were made through a window. Carbon monoxide and smoke indicating instruments were in the basement, as already described. Here, too, were the controls for the radiant heat source and the ignitor, as well as the recording potentiometer used with the thermocouples.

The duration of the tests varied. Active flaming was usually the criterion for ending a run. Where termination occurred before the inception of flaming on the specimen, the end point was usually defined as the time at which it was estimated that all or most of the volatiles had been distilled from the specimen. It was considered that further flaming would not occur, or if it did, would represent the ignition of only the carbonized remainder of the panel.

4. Results of Tests

The duration of the several tests is shown in Table 1, together with an indication of whether or not termination of a trial was brought about by the incidence of active flaming. The table also gives the temperatures determined from the thermocouple readings. Where a temperature is shown as being more than 600°C, it indicates that the actual temperature on a flaming specimen exceeded the top of the scale of the recording potentiometer. Temperatures at the floor and ceiling of the test room are included to give some details of the temperature rise above the ambient caused by the heat from the electric burners and from the combustion of the specimen.

Table 1. Results of Tests

Test No	Description of Specimens	Power to Heater	Specimen Backing and Protection[2]	Spec. Temperature Prior to Ignition Front	Spec. Temperature Prior to Ignition Back	Time to Ignition	Test Duration	Max. Specimen Temperature Front	Max. Specimen Temperature Back	Max. Room Temperature Ceiling[3]	Max. Room Temperature Floor[4]	[illegible] Index
		kw		°C	°C	hr:min	hr:min	°C	°C	°C	°C	I_s
1.	Hardboard; 1/4 in; Unfinished; 60 lb/ft^3	6.2	b	386	374	3:56	5:17	>600	572	330	86	[illegible]
2.	Cane fiberboard; 1/2 in.; Factory finish; 18 lb/ft^3	6.2	a	260	158	0:55	0:55	-	560	134	54	[illegible]
3.	Plywood, Exterior gr.; 1/2 in.; 39 lb/ft^3	6.2	a	254	254	5:10	7:20	570	596	226	80	[illegible]
4.	Laminated Paperboard; 3/8-in.; Factory finish; primer; 35 lb/ft^3	6.2	a	270	96	0:35	0:35	>600	208	274	66	[illegible]
5.	Laminated Paperboard 3/8-in.; Primer and alkyd paint (500 ft^2/gal)	6.2	b	280	198	4:45	4:45	364	238	144	68	[illegible]
6.	Acoustical tile; 1/2-in.; Screwed on asbestos millboard; 17 lb/ft^3	6.2	b	-	-	No Ign.	5:00	222	166	84	54	[illegible]
7.	Polystyrene Wall tile; 4-1/4 x 4-1/4 x .068 in.; Cemented on gypsum bd.; 65 lb/ft^3	6.2	b	-	-	No Ign.	5:00	232	188	88	58	[illegible]
8.	Wood veneer, cloth backed; on 1/2-in. gypsum board; 52 lb/ft^3 1/	6.2	b	-	-	No Ign.	2:25	250	126	76	[illegible]	[illegible]
9.	Vinyl coverd cloth on 1/2-in gypsum bd.; 54 lb/ft^3 1/	6.2	b	-	-	No Ign.	1:25	180	164	66	36	[illegible]
10.	Hardboard; 1/4 in.; Unfinished; 60 lb/ft^3	11.6	a	-	-	0:23	0:23	-	-	-	-	[illegible]
11	Hardboard; 1/4 in.; Unfinished; 60 lb/ft^3	11.6	c	418	228	1:05	3:15	540	>600	120	58	[illegible]
12.	Laminated Paperboard; 3/8-in.; Factory finish and primer; 35 lb/ft^3	6.2 and 11.6	c	464	350	1:30	1:30	580	>600	110	44	[illegible]
13.	Cane fiberboard; 1/2-in.; Factory finish; 18 lb/ft^3	6.2	c	474	150	0:25	1:00	>600	>600	90	50	[illegible]
14.	Plywood, Exterior gr.; 1/2-in.; 39 lb/ft^3	11.6	c	308	230	0:41	0:50	460	>600	90	36	[illegible]
15.	Charcoal Briquettes; 4 x 6-in. size; 12-1/2 lb	-	-	-	-	Approx. 10:00	10:55	-	-	112	[illegible]	-
16.	Wood Fiberboard; 1/2-in.; Starch glaze; 20 lb/ft^3	-	-	-	-	No Ign.	10:45	-	-	115	[illegible]	[illegible]

1/ Density of assembled finish material and backing

2/ a = air backing; b = millboard backing; c = millboard backing with metal plate 1/2 in. in front of specimen.

3/ Above specimen

4/ 2 ft above center of floor

Fig. 1. Test House

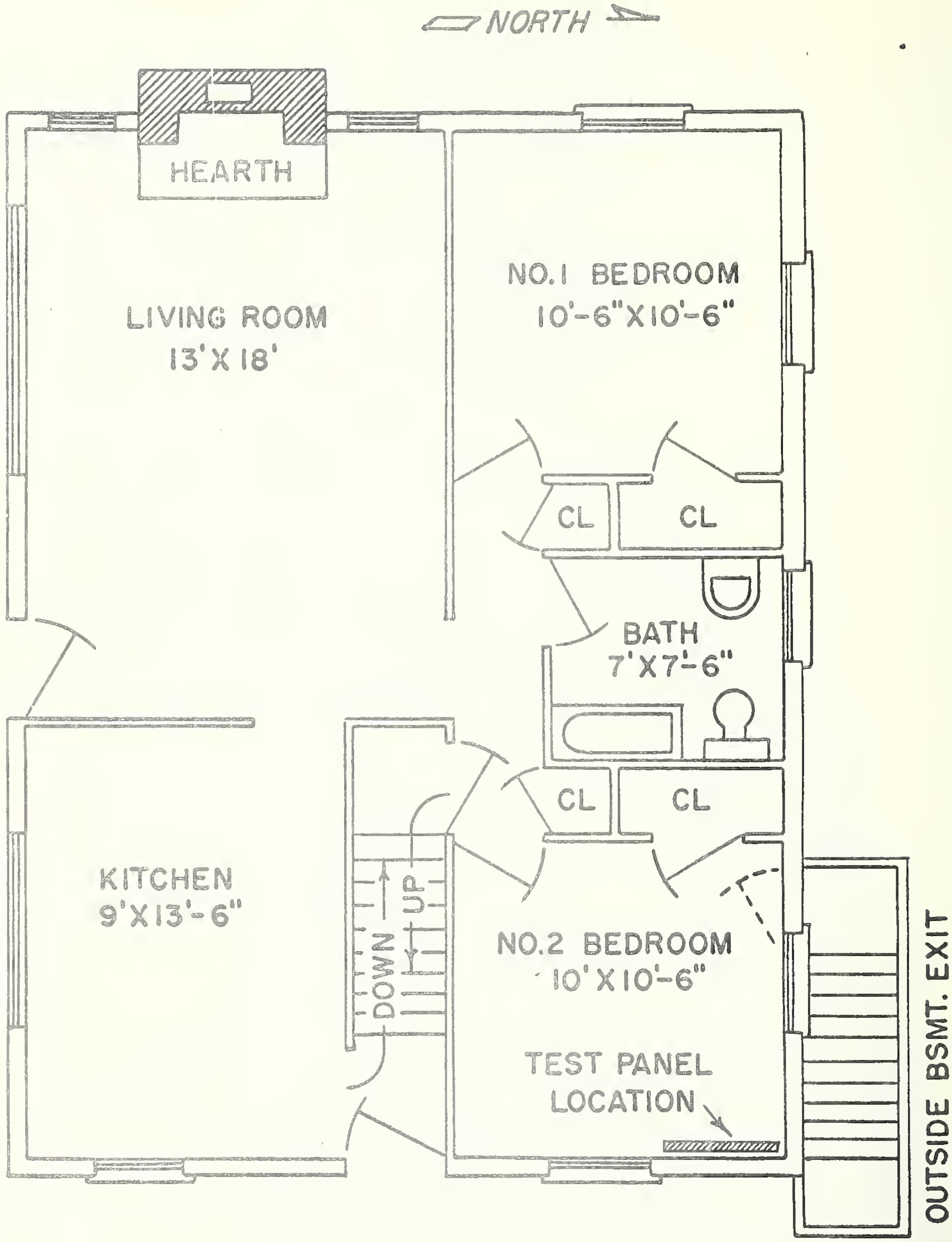

FIG.2-PLAN OF TEST HOUSE

HOUSE WAS BRICK VENEER OVER FIBERBOARD SHEATHING. MINERAL WOOL BATS BETWEEN OUTSIDE WALL STUDS AND CEILING JOISTS. INTERIOR WALLS GYPSUM LATHED AND PLASTERED. ATTIC AND FULL BASEMENT UNFINISHED. NO.1 AND 2 BEDROOMS HAD 3'X 5' DOUBLE HUNG WOODEN WINDOWS WITH FULL LENGTH WOODEN STORM SASH.

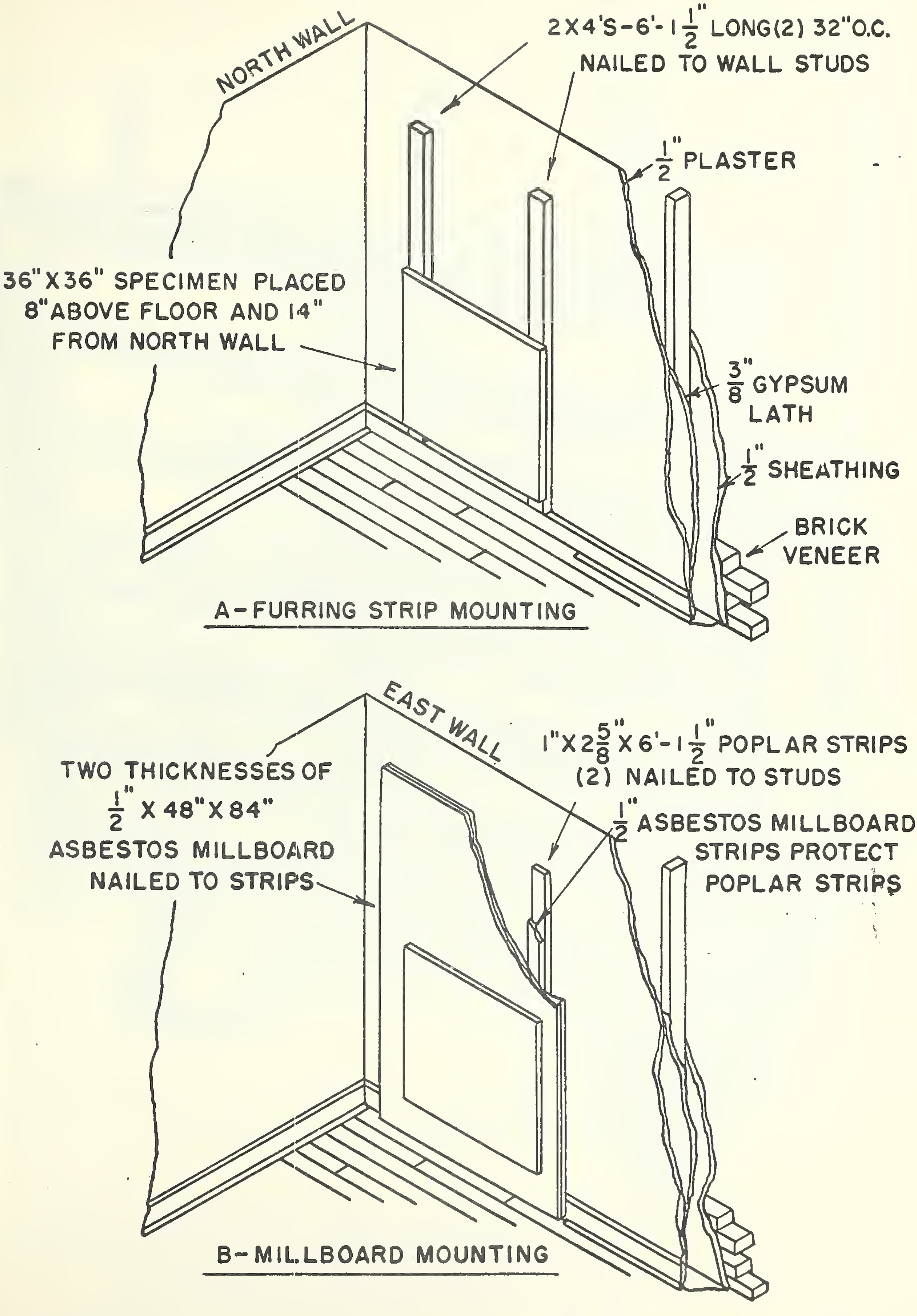

FIG. 3 - METHODS OF MOUNTING SPECIMENS

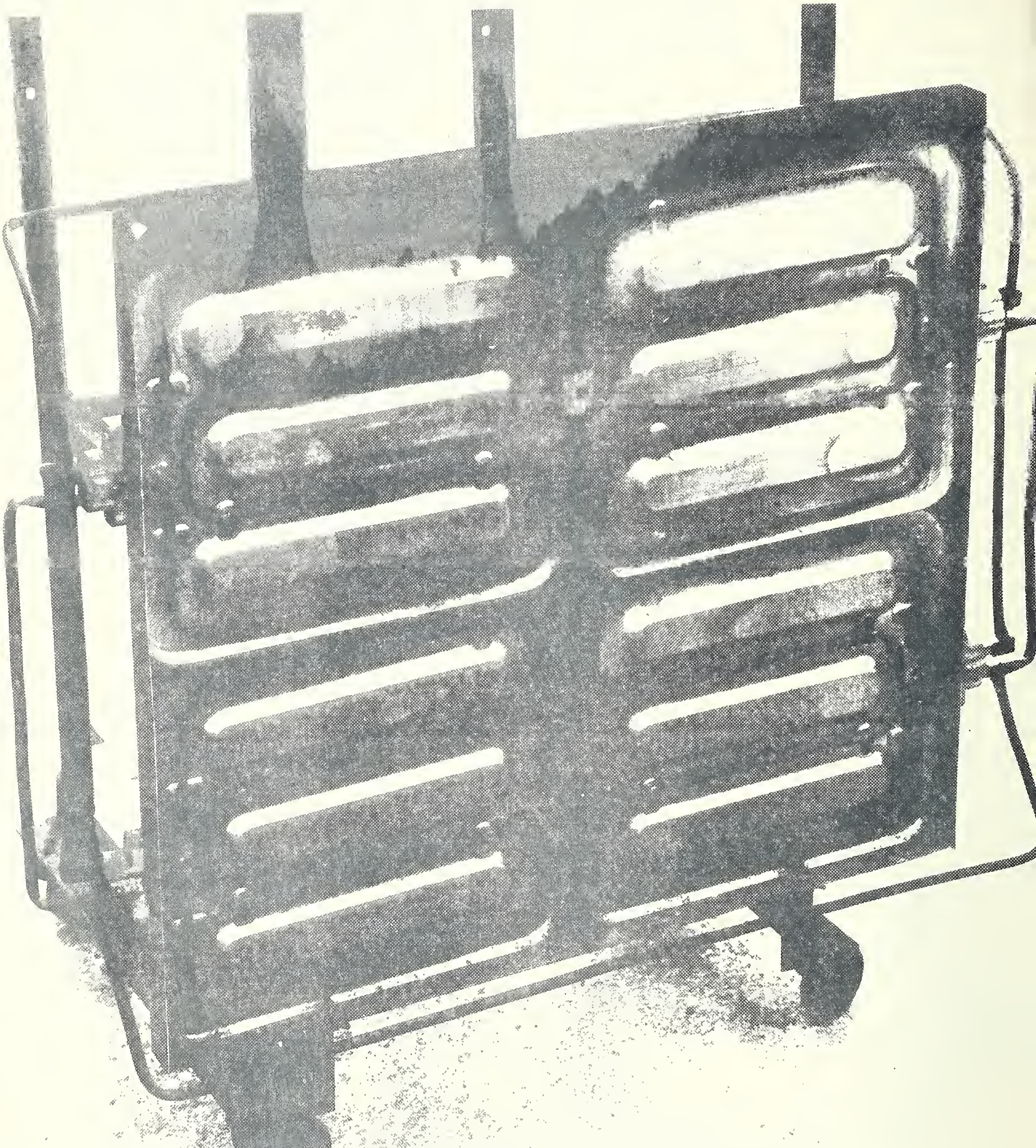

Fig. 4. Radiant Heat Source

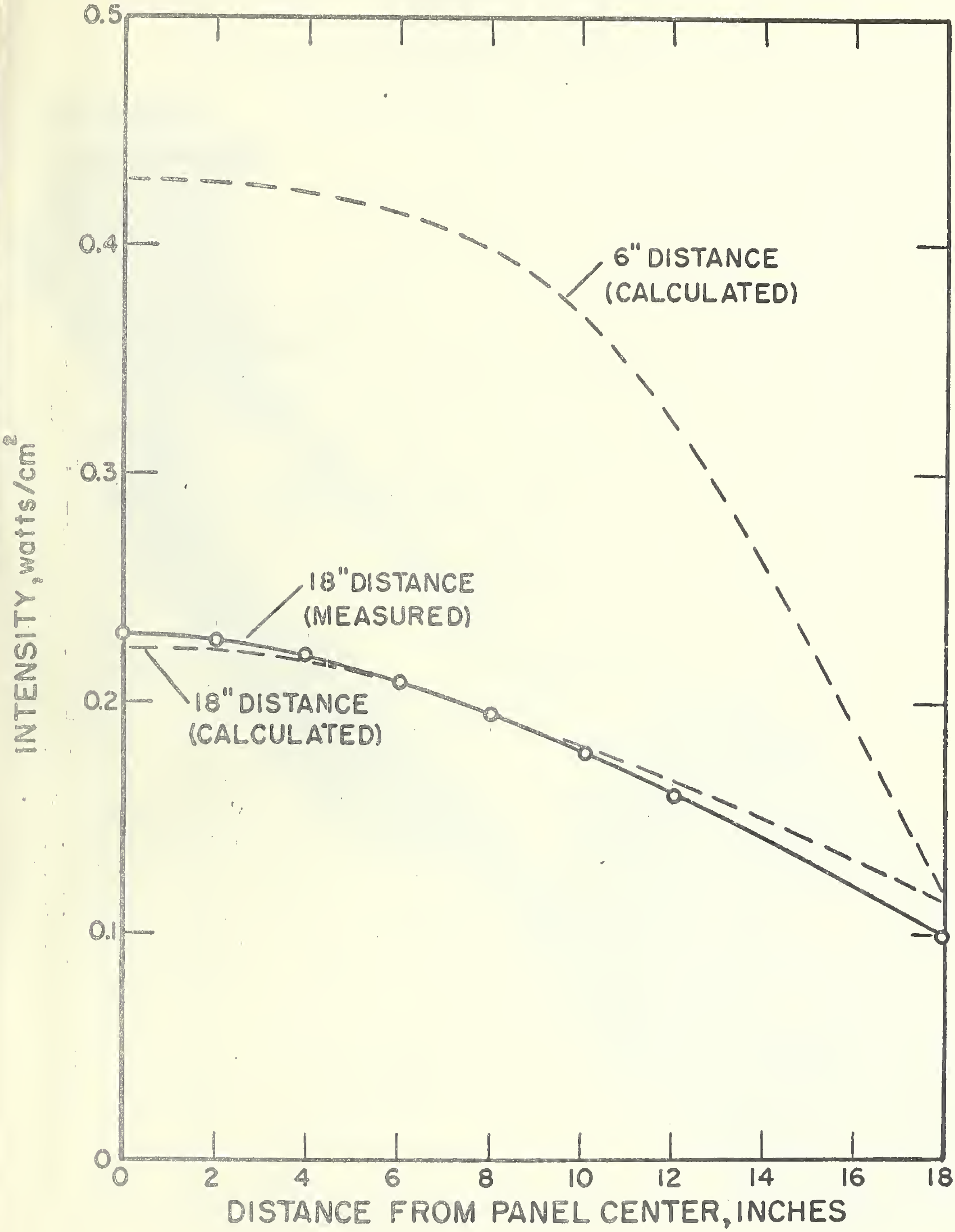

FIG.5 - MEASURED AND CALCULATED RADIANT INTENSITIES ON TEST SPECIMEN FOR A HEATER INPUT OF 6.2 kw

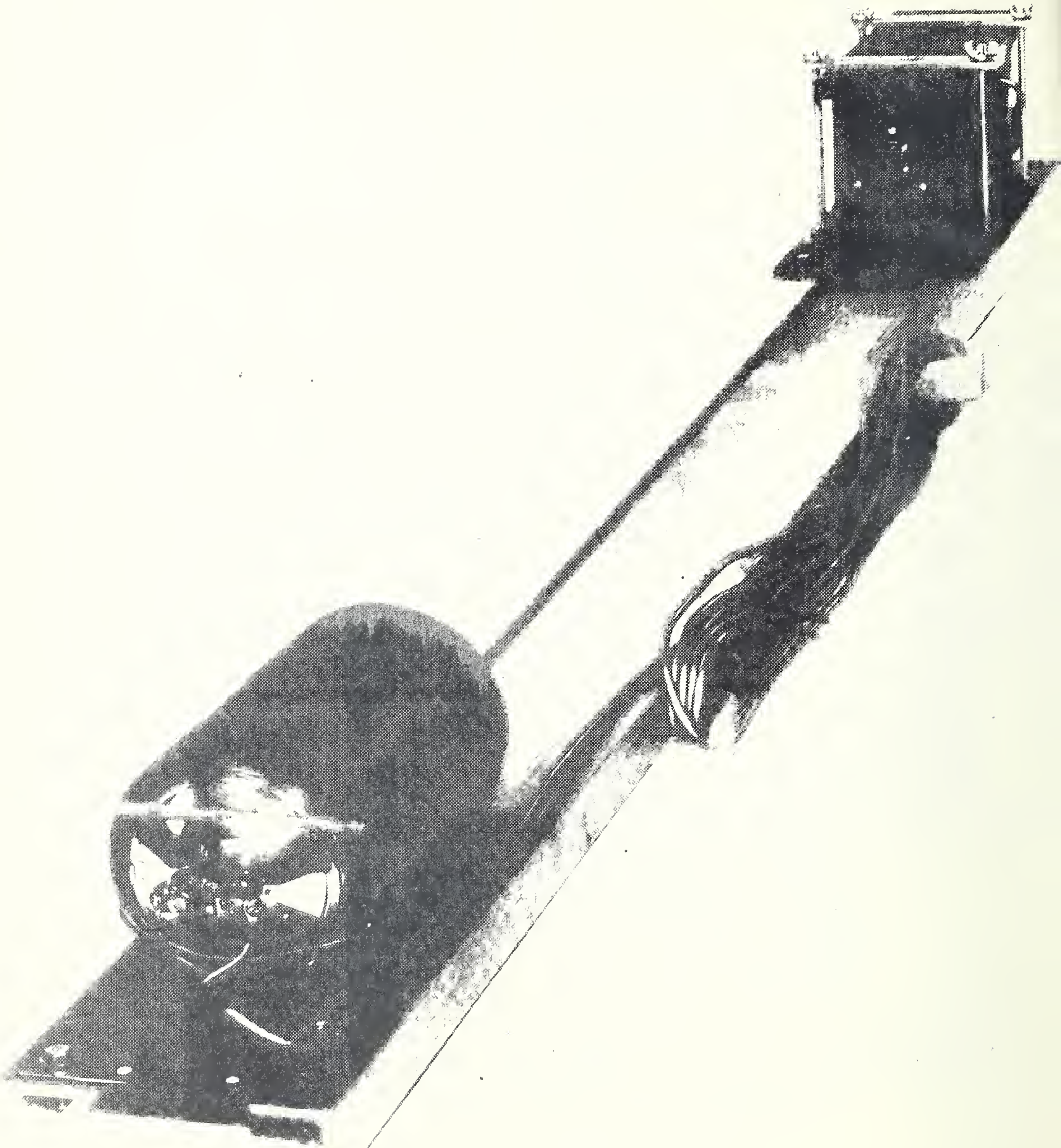

Fig. 6 Smoke Meter. Housings for Light Source (left) and Photo-Electric Cell (right).

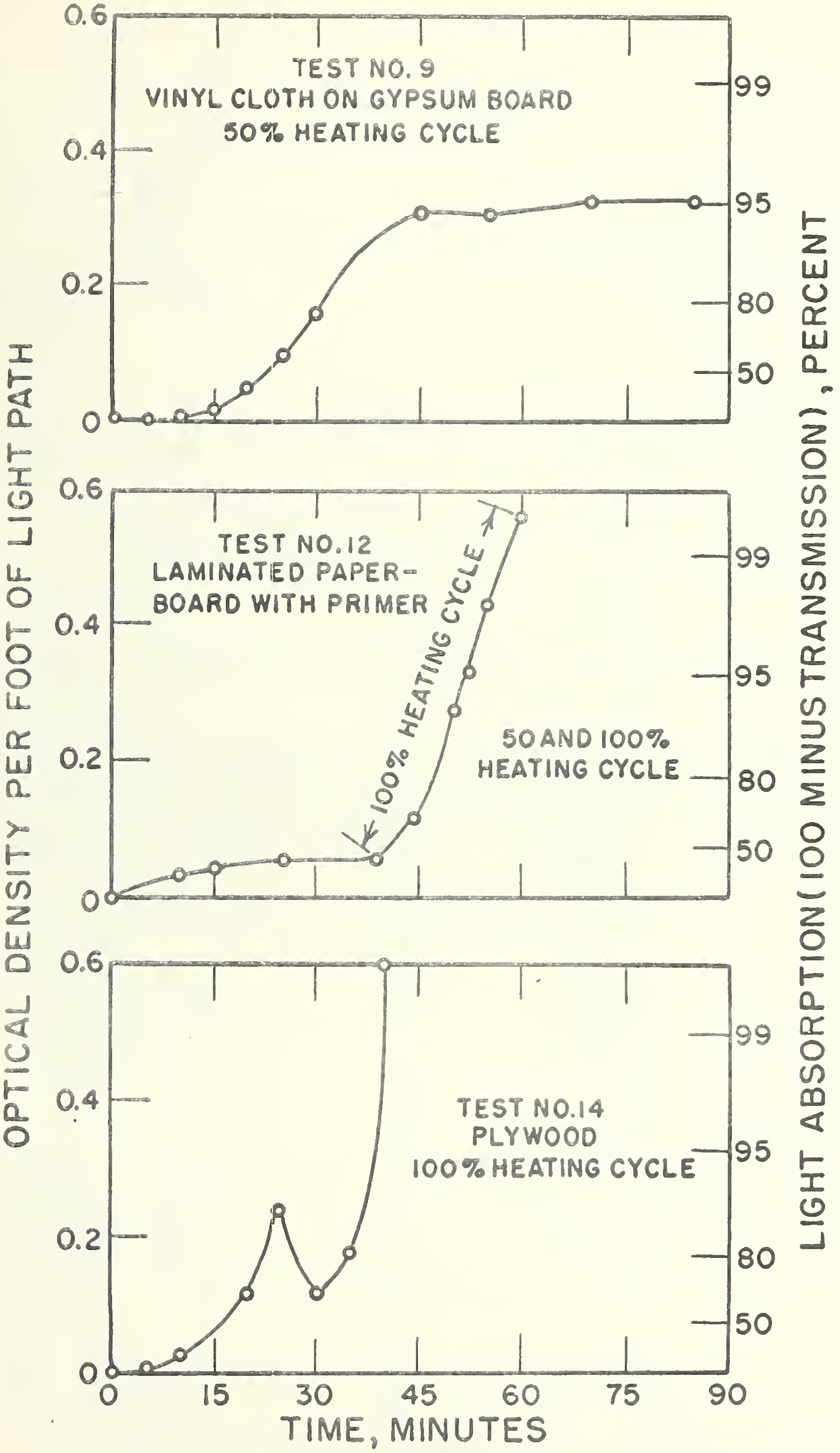

FIG. 7 — SMOKE MEASUREMENTS AT CENTER OF ROOM DURING TESTS

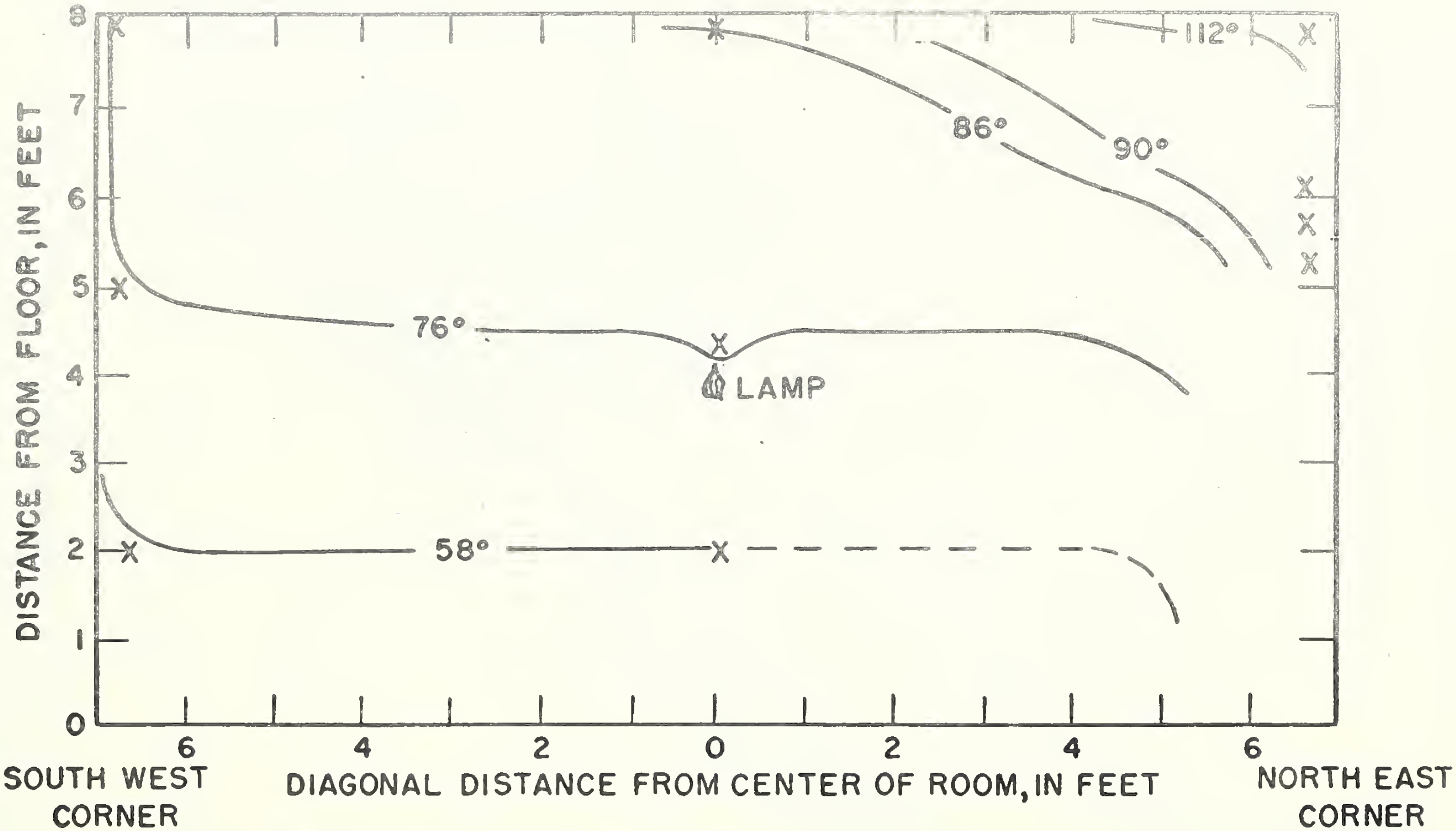

FIG. 8 – TEST ROOM TEMPERATURES, IN °C, JUST PRIOR TO IGNITION OF SPECIMEN IN TEST NO. 11

NOTE: X INDICATES THERMOCOUPLE LOCATION

Table 2. Smoke Measurements and Observations

Test No.	Optical Density/ft light path			Times		Smoke by Radiant Panel	Remarks
	At 10 min	Max.	At test end	To max. dens. hr:min	To test end hr:min	mg.	
1.	-	-	-	Approx. 1:00	5:17	2.6	Dense at 20 min.
2.	-	-	-	Approx. 0:50	0:55	0.2	Light to 30 min.
3.	-	-	-	Approx. 1:00	5:10	0.3	Room filled at 40 min.
4.	-	-	-	Approx. 0:30	0:35	-	Dense at 20 min.
5.	-	-	-	Approx. 1:10	4:45	1.1	Slow build-up.
6.	0.016	0.042	0.001	0:25	5:00	0.3	
7.	0.008	0.134	0.023	1:30	5:00	10.6	
8.	0	0.046	0.048	2:20	2:25	0.7	
9.	0.006	0.320	0.320	1:10	1:25	3.8	
10.	-	-	-	Approx. 0:20	0:23	2.6	Very dense
11.	0	0.450	0.146	0:50	3:15	2.6	
12.	0.031	0.550	-	1:00	1:30	-	
13.	0.002	0.630	0.370	0:30	1:00	0.2	
14.	0.024	0.600	-	0:40	0:50	0.3	
15.	-	0.390	0.015	0:30	10:55	-	

For these tests in which actual measurements were made, values for smoke production are shown in Table 2. In the absence of a standard for photoelectric smoke measurements, the smoke concentrations have been reported on the basis of optical density per foot light path, $(1/d)(\log_{10} 100/T)$ where T is the percent transmission, and d is the length of the light path in feet. Optical density was used because it has a more nearly linear relationship to smoke concentration than does absorption or transmission. The smoke measuring apparatus was not available or not operative in some of the tests. For these, an indication of visually observed smoke conditions is included.

Because of difficulties with the operation of the carbon monoxide detection device, only scattered data are available for this phase of the investigation. Representative readings ranged from a low concentration of 0.04 percent CO in Test 12 to highs of 0.12 percent in Tests 11 and 14. The gas was also detected in Test 13 where readings of 0.05 percent were observed at two separate intervals. In Test 15 (charcoal briquettes), the presence of some carbon monoxide was noted throughout most of the trial, with a high meter reading of 0.11 to 0.12 percent.

In none of the tests of the panels was any flashing of combustible gases noted at the electrode ignitor, which was periodically energized. However, in the test with the charcoal briquettes, an ignition flash was observed to occur after about 8 hr. smoldering. The ignition was not of a force to cause damage to the structure, and was not sustained.

The small lamp, fueled with kerosene or alcohol, and centrally located in the room, did not in any of the tests indicate the presence of combustion inhibiting gases in a quantity sufficient to cause its extinction. Where extinction of the lamp did occur, it was found to be due to fuel depletion in the later stages of a test of long duration.

In the two tests not involving panels, 15 with charcoal briquettes and 16 using massed sheets of wood fiberboard, considerable smoke was produced from the materials which were allowed to smolder after removal of the initiating heat. In both cases the tests were continued for more than 10 hours. Some flaming occurred in the charcoal near the end of the trial, but this was neither intense nor extensive. The wood fiberboard appeared to smolder only, with no flaming detected by visual observation or rise in temperature on an adjacent thermocouple.

5. Discussion of Results

Perhaps the most notable feature of the test was the very large amount of smoke produced by the exposure, to a radiant heat source, of only 9 ft^2 of wall finish material, sometimes in a thin sheet, and never exceeding 1/2 in. in thickness. This smoke, in a very few minutes, could fill and make untenable a room of approximately 800 ft^3 volume. The development of this smoke condition, as indicated by the smoke meter readings in three of the tests, is shown by the curves in Figure 7.

Correlation of the smoke output in these tests with the smoke production during the radiant panel flame spread tests was not always possible, nor could it be expected under the differing bases and conditions of the two types of investigation. Smoke in the radiant panel test is the product of more or less active flaming of a specimen, and is measured as the weight or optical density of a continuous particle deposit over a period of 15 min. In the tests of this report, smoke measurements were made on the output of a heated but not flaming surface, with light transmission observations only made periodically during the trial.

These differences in the characteristics measured could account for the lack of correlation between the flame spread smoke determination and that reported here for the vinyl cloth (Test 9). This material showed a high deposit of smoke particles during flame spread test (second highest of those tested), but ranked considerably better on the basis of smoke optical density in the test room. The polystyrene tiles (Test 7) were not exposed to radiation to the extent intended, as by 1-1/2 hr after the start, most of them had buckled and fallen from their gypsum board backing panel, and were thus no longer in the radiation field. None of these tiles showed any evidence of ignition. The smoke produced by this specimen apparently resulted from the exposure of the tile adhesive and gypsum board backing.

In three of the tests, hardboard was the panel material. For two of these (Tests 10 and 11) the radiant exposure was the same at 11.6 kw heater input. There were differences in the method of mounting, however, the panel of Test 10 being mounted on furring strips and with no protection in front, that of Test 11 flush against a millboard backing and with a metal plate between the specimen and heat source.

Although it would appear that lack of an air space behind the specimen of Test 11 would increase the likelihood of early ignition, the protection afforded by the presence of the steel plate in front increased the time to ignition by a factor of approximately three (23 min in Test 10, and 65 min in Test 11). With the heater on 50 percent of the time (6.2 kw), as in Test 1, the time to ignition was increased to 3 hr 56 min, as compared to 1 hr 5 min in Test 11, even though the similarly mounted panel had no protective shield (Test 1). The shielding capacity of the metal plate appears to be further exemplified by a comparison of Tests 4 and 12. In Test 4, the laminated paperboard was mounted on furring strips to give an air space at the back. The specimen in Test 12 was applied to millboard and had a metal shield 1/2 in. in front. The heating panel was on 50 percent of the time in Test 4, and for the first 40 minutes of Test 12, after which it was changed to 100 percent duty. The comparable ignition times were 35 min in Test 4 and 1 hr 30 min in Test 12, with more than half of the latter time at full radiant intensity.

This trend, however, appears to be contradicted in Tests 2 and 13, where the former was mounted with an air space behind, the latter having a millboard backing and the protective metal shield in front. With a heater input of 6.2 kw in both tests, the duration in Test 2 was 55 min as against 25 min in Test 13. In the case of plywood, the metal plate appeared to offer little protection against an increase in the intensity of the exposure. An approximate 5-hr duration to ignition at 50 percent exposure (Test 3) was reduced to 41 min at 100 percent (Test 14), notwithstanding the presence of the plate in the latter trial. Although the extent of the protection provided by a steel plate placed in front of the specimen is questionable, there is a possibility that, had it been feasible to mount the shield to allow free vertical flow of air between it and the face of the specimen, a greater protective effect would have resulted.

It was noted, also, that where the steel plate was interposed before the specimen, a greater temperature rise occurred on the back surface of the specimen than on the front, Tests 11-14). This can be attributed to a self-heating phenomenon on the back surface, which because of the insulating effect of the millboard backing and the specimen itself, probably occured at a faster rate than did the heating of the front surface protected as it was by the metal shield.

The laminated paper board material of Test 4 showed greatly improved resistance to ignition when treated with single applications of primer and alkyd paint (Test 5). The same phenomenon had been noted for this material, similarly coated, when examined for flame spread properties by the radiant panel method.

From the temperatures measured in the room during a test, it was noted that flaming of the specimen usually resulted in greater temperature rises at the ceiling than did prolonged heating, even in tests extending to 5 hrs. In Tests 11-14 with the steel plate, however, the ultimate ceiling temperature was only a little higher than that in tests in which no flaming occurred, possibly due to an inhibiting effect on the flame through lack of oxygen caused by the proximity of the plate to the burning surface. A plot of isothermal lines in the room just prior to ignition of the hardboard specimen in Test 11 is shown in Fig. 8.

6. Conclusions

It was apparent from the tests that many building finish materials would give off smoke and acrid fumes when exposed to a radiant heat source such as might result from an overheated stove, furnace, or chimney. The very large volume of smoke produced by test panels of limited size indicates that, even if only a small area of wall surface is exposed, a serious hazard may develop. The presence of carbon monoxide was noted in the tests, and ignitable mixtures could be generated by prolonged heating of carbonized wood.

The radiant heat source, as described, could also present an ignition hazard, as many of the panel materials, after varied exposure durations, were brought to a state of active flaming. There was some evidence, however, that, by shielding or for certain materials, by suitable surface application, the inception of flaming may be considerably delayed, although smoke production would not necessarily be curtailed.

An extension of the program of work reported here appears to be warranted. If a suitable test structure could be made available, it would be especially profitable to investigate means of providing protection to structures that may be adjacent to a heat source. Also, in light of the now recognized danger from smoke and fumes, a project to determine what methods or materials are required to mitigate this hazard may well be instituted.

7. References

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