NATIONAL BUREAU OF STANDARDS REPORT

1947

FIRE HAZARD TESTS OF SUBSTITUTE DUCT MATERIALS

by

A. C. Hutton
and
D. Gross

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ABSTRACT

The results of a number of tests performed for the purpose of establishing criteria for evaluation of the fire hazard of substitute materials for metal ducts are presented. The procedures used to appraise the self-heating, ignition, flame spread and combustibility characteristics are described. Included also is a description of a test on a large scale mock assembly of a duct system demonstrating the flame spread hazard of combustible ducts. Although the testing procedures are by no means "standard", the use of the results obtained is suggested as a basis for evaluation of the fire hazard of substitute duct materials.

1. INTRODUCTION

A request was made by the Housing and Home Finance Agency that the Building Technology Division establish criteria for evaluating substitute materials for metal ducts. The Fire Protection Section was asked to perform tests which would furnish data which might be used as a basis for specification of criteria for selection of such materials. Two materials were made available for investigation with the suggestion that determinations be made of the temperatures at which self-heating and ignition occur and of the flame-spread characteristics of these materials.

2. TEST MATERIALS

Material samples furnished for preliminary evaluation consisted of:

"Sonoairduct Laminated Fiber Tubing" of 8-in. inside diameter, 8 1/2-in. outside diameter, manufactured by the Sonoco Products Company, Hartsville, South Carolina. It was supplied in 4-ft and 18-ft lengths and could be cut to any desired length with a hand saw. To join straight sections, outside collars of the same material and thickness and 12 in. long were supplied by the manufacturer. The cellulose ply tubing was analyzed as having approximately 50 percent chemical wood and 50 percent ground wood and had a paraffin-wax coating on both exposed surfaces, and

"Sal-Mo No.77 Asbestos Duct Board," manufactured by the Sall Mountain Company, Hamilton, Ohio. The board comprised an admixture of asbestos and approximately 16.5 percent of combustible material including cotton. Both surfaces were finished with a thin, black coating. An attached label carried the following manufacturer's specifications: "Size of sheet 33 in. x 48 in.; Thickness 1/8 in.; weight per sheet 7 lb; square feet per sheet 11 sq ft; sheets per carton 16 sheets; weight per carton 114 lb."

3. TESTS

The primary purpose of the investigation was the performance of tests from which criteria could be established for evaluation of the fire hazard of substitute duct materials. The development of standard test procedures and the determination of properties of the particular materials submitted were considered secondary. Therefore, tests were designed to indicate the minimum safe requirements for duct materials in general, and were carried out with the use of whichever of the two test materials proved more suitable in form.

3.1 Self-Heating and Self-Ignition Characteristics

At the steady-state temperatures normally found in warm-air ducts, it was not considered probable that self-ignition (ignition in the absence of a directly applied high-temperature source) of the duct, or of combustible materials in contact with the duct, would occur. Abnormal temperature conditions may prevail, however, for circumstances where the bonnet protective limit control fails or when ignition of an accumulation of combustible trash in the duct produces a localized heat source. Inasmuch as the performance of a duct material may be influenced by the properties of combustible materials used as covering for, or in contact with the duct, it seemed desirable to consider this influence on the tendency of developing self-heating in the composite section. With this in mind, a test was designed utilizing a short section of a typical warm air heating duct assembly. This section was judged to offer a degree of fire hazard which may be significant in assemblies using substitute materials. For these tests, duct materials of sheet form were used, although a similar arrangement for round ducts could also have been used.

This testing arrangement (see Fig. 1) comprised a one-foot length of a 3-in. by 12-in. duct section surrounded on the sides by a single layer and on the top and bottom by a double layer of 1/2-in. insulating-fiberboard sheet, a common insulating material. The ends were left open. A micro burner was mounted with its stem projecting vertically 2 1/4 in. from the lower duct surface. A thermocouple (A) placed at the center of the two upper insulating boards enabled a continuous temperature recording to be made on an electronic potentiometer recorder. The temperature measured between the two insulating boards for a given exposure resulted from the composite effects of heat conduction through the duct and backing and self-heating in the duct and backing. These heating effects are influenced by the ability of the duct material both to reflect radiant heat and to diffuse heat along the duct, as well as by the tendency of the duct material to separate from the backing.

Two preliminary tests were run in which a pile of wood chips and cotton lint was ignited and temperature curves were obtained. These curves were then duplicated using a gas flame which has the advantage of being reproducible. The "standard" gas consumption history chosen is given in Fig. 1. The total area of the stepped fuel-time chart was made equal to 0.400 ft^3, corresponding to a heat input of about 440 Btu for the natural gas used. This is approximately 80 percent of the higher heating value of the wood chip pile, the burning of which is known to be not entirely complete.

Tests were run with Sal-Mo Asbestos Duct Board, asbestos millboard (1/8 in. thick and containing less than 3 percent combustibles), galvanized iron (U.S. standard gage No. 25), black iron (U.S. standard gage No. 24), aluminum (Brown and Sharpe gage No. 24), graphite coated aluminum and Sal-Mo Asbestos Duct Board with an aluminum foil surface. The metal ducts were stiffened by giving them a slight diagonal crimp similar to fabrication practices in duct installations. These ducts were fastened to the fiberboard backing at the center of each edge to maintain the maximum contact area during heating. Although this reduced somewhat the inward buckling tendency, separation of the metal duct occurred in each test to varying degrees, whereas very little separation was noticed for the nonmetal ducts.

The results (Fig. 2) indicate a marked difference between the characteristics of the metal ducts and the asbestos-base ducts. Tests using the latter duct materials resulted in ignition of the upper layers of fiberboard backing, whereas tests with metal ducts resulted in peak temperatures no higher than about 212°F (100°C).

The effect of the emissivity of the duct surface was indicated in two of the tests. In one test, the emissivity of the aluminum was increased by applying to it a coating of graphite over a graphite plus varnish undercoat. When tested, a slightly higher temperature at point A, Fig. 1, resulted than had been obtained with the shiny aluminum duct. In a second test, Sal-Mo Asbestos Duct Board was covered with a low emissivity surface by cementing a sheet of aluminum foil to a duct which had previously been given a coating of aluminum paint. This resulted in ignition of the fiberboard, as with the plain Sal-Mo Asbestos Duct Board. Thus the ability of the duct material to absorb radiant heat (as measured by surface emissivity) appears to have only a slight effect upon heat retention.

It appears reasonable, therefore, to attribute the decided differences between the local heat-transmission characteristics of metal and nonmetal ducts to the physical separation between the metal duct and its backing which results under fire exposure. Thus, metal ducts covered with combustible materials present less fire hazard than similarly covered nonmetal ducts, including asbestos, when subjected to a fire such as might be caused by the ignition of an accumulation of wood chips, lint, etc.

3.2 Flame-Spread Characteristics

Three test procedures were used to investigate flame-spread characteristics: a flame-spread demonstration test, an ease-of-ignition test, and a flame-spread comparison test.

3.2(a) Flame-Spread Demonstration Test of Sonoairduct

This material was chosen since it was considered the more likely one for demonstrating flame-spread hazard. The test was performed to provide a visual demonstration of the flame-spread characteristics of the laminated tubing under a set of conditions which might occur in warm-air heating applications.

A 9-ft section of the tubing was embedded in dry sand enclosed in a wooden frame (see Fig. 3). There was approximately 1-1/2 in. of sand both above and below the duct and 2 1/2 in. of sand to each side. A 9-in. 90-degree galvanized-iron elbow was fitted over a laminated-tubing collar which fitted in turn over one end of the duct. A 9-in. round to 9-in. by 12-in. rectangular aluminum transition piece completed the duct circuit to a floor register with a 7 1/2-in. by 12-in. opening. An 8-ft high plasterboard panel placed vertically 6 in. from the register and topped by a similar plasterboard sheet, horizontally placed, represented the wall and ceiling respectively. The wall was given a coat of a rubber-base blue paint.

The other end of the duct was enclosed in a chamber which contained a 2000-watt heater and through which an electric fan forced heated air into the duct. A removable plate-glass cover permitted both the placing of material into the duct mouth and the application of an ignition source to it. Through the glass cover, visual inspection was possible without disturbing equilibrium conditions. The electric fan was connected through a variable ratio transformer, permitting adjustment of fan speed over a considerable range. A mercury thermometer and anemometer were placed at the register to obtain outlet temperature and velocity readings.

When equilibrium conditions, 171°F (77°C) and 190 ft/min, were established at the register, a handful of loose excelsior was placed in the partly delaminated mouth of the duct at the upstream side. The excelsior was ignited. As the flames progressed along the duct, the evolution of gas produced a mixture toward the register end too rich for burning. Increasing the air velocity to approximately 400 ft/min accelerated the flame spread through the duct and out of the register. Flames reached a maximum height of about 7 ft up the wall, and then diminished as the duct collapsed at its approximate mid-length. 16-mm color motion pictures were taken of the demonstration.

Inasmuch as the laminated tubing was designed specifically for embedment in concrete floor slabs, and since duct collapse during the test was due to the sand (which was to have represented the concrete), a second test using concrete was performed. Ordinary Portland-cement concrete (1:2:4) replaced the sand in the wooden frame and, in addition, surrounded the galvanized-iron elbow and transition piece up to the floor level to simulate poured concrete-slab construction. The concrete extended the full length of the duct with the exception of 6 1/2 in. at the duct mouth. The distance from the center of the register to the duct mouth was 9 1/2 ft. Fig. 4 shows a view before test of the floor and register, with asphalt-tile flooring partly laid. A view of the concrete-embedded duct, heating chamber, fan, and other details of the testing arrangement before test are shown in Fig. 5. The test procedure was identical with that used in the previous test.

Table 1 is a composite log combining observations taken during the latter test with those read from 16-mm colored motion-picture film taken of the first three minutes of the test. The latter is available for projection upon request.

Table 1

Test Log

Time hr:	min:	sec:	Observation
12:	00:	00	Test begins with ignition of excelsior. Equilibrium temperature 174°F (79°C). Air velocity 155 ft/min.
12:	00:	06	Smoke appears at register.
12:	00:	30	Smoke from burning excelsior stops.
12:	00:	33	Smoke from burning duct appears at register.
12:	00:	45	Smoke extends full width of panel (4 ft) and reaches ceiling height (8 ft).
12:	00:	50	Fan speed increased to 470 ft/min. Flames appear at register. Smoke decreasing.
12:	00:	55	Flames to 4-ft level, 2 ft wide.
12:	01:	00	Flames to 8-ft (ceiling) level, 3 ft wide.
12:	01:	25	Flames to 7-ft level, 2 ft wide.
12:	01:	45	Baseboard burning.
12:	02:	05	Flames to 6-ft level, 2 ft wide.
12:	02:	20	Flames to 4-ft level, 2 ft wide.
12:	02:	35	Flames backing out of duct mouth cause ignition of wooden plenum chamber. This necessitates removing fan for a few seconds to prevent damage to heating equipment. This causes flames at register to cease.
12:	02:	45	Flames reappear to 3-ft level.
12:	02:	55	Flames to 4-ft level.
12:	05:	00	Flames to 1-2 ft level.
12:	06:	00	Flames to register level. Blistering and burning of asphalt tile evident up to 5 in. around a dull red grill.
12:	08:	00	Occasional licks of flame still visible at transition piece; small pieces of duct, still glowing, being blown through register.
12:	11:	00	Flames cease entirely with duct glowing.
12:	20:	00	Duct continues to glow. Water applied.

Fig.6 is a view of the concrete duct casing after the test, showing the few charred pieces of an otherwise burned-out duct. A front view of the floor and plasterboard wall, after the test, is shown in Fig. 7. Discoloration is evident to a height of 53 in. above the floor, and the baseboard shows charring which extends 6 in. to either side of the register. Blisters to 7 in. and charring to 4 in. from the register appear on the asphalt tile floor.

3.2(b) Ease-of-Ignition Test

An ease-of-ignition test was performed to determine the relative ease in obtaining a self-sustaining flame in the laminated tubing, and to supplement the previous test described in 3.2(a). To indicate the relative ease of producing a self-sustaining flame in the tubing, a test designed to simulate the accidental dropping of a lighted match through a wall or floor register on to an accumulation of oily lint, dust, or other waste was devised.

The procedure consisted of placing a lighted match (wood splint safety match) on oil-impregnated cotton batting at each of two different duct locations - at a collared joint and on the free duct surface (see points A and B, Figure 8). Varying quantities of cotton impregnated with different quantities of fuel oil were used to simulate accumulations representing conditions which might be found in duct systems below furnace level. A fresh portion of duct was used for each test, and successive tests were designed to provide increasingly severe igniting conditions. In this manner it was possible to determine the conditions necessary to produce a self-sustaining flame resulting in ultimate ignition of the duct. However, all of the tests were conducted with an unheated duct and no air flow, a situation less conducive to ignition than that of actual use.

Table 2 lists the tests performed, indicating the quantities of No. 2 fuel oil and cotton batting used at each location.

Table 2 - Results of Ease of Ignition Test

POSITION A*

Test	Weight of Cotton Batting gm	Volume of No. 2 Fuel Oil cc	Remarks**
1A	0.0	0.0	No ignition
2A	0.0	5.0	do
3A	2.0	0.0	Ignition of cotton only.
4A	0.5	5.0	Ignition of fuel - soaked cotton only
5A	1.0	2.5	do
6A	1.0	5.0	Self-sustaining flame in duct

POSITION B*

Test	Weight of Cotton Batting gm	Volume of No. 2 Fuel Oil cc	Remarks**
1B	0.0	0.0	No ignition
2B	0.0	5.0	do
3B	2.0	0.0	Ignition of cotton only
4B	2.0	2.5	Ignition of fuel - soaked cotton only
5B	1.0	5.0	do
6B	2.0	5.0	Self-sustaining flame in duct

* See Fig. 8

** The primary ignition source was the match which was only partly consumed in all but those tests which developed a self-sustaining flame.

It will be noted from the above table that flaming ignition of the duct resulted when 5 cc of fuel oil added to 1 gram of cotton batting placed at Position A (or when 5 cc of fuel oil added to 2 grams of cotton batting placed at Position B) was ignited by a match. The tests have thus shown that ignition of the laminated duct will result under conditions neither excessive nor severe.

3.2(c) Flame-Spread Comparison Test

A flame-spread comparison test was made to determine the flame-spread characteristics of the two products under comparable conditions. Both materials were tested in the form of round ducts. This was accomplished by molding a moistened sheet of Sal-Mo Asbestos Duct Board around an 8-in. O.D. metal pipe and and permitting it to dry completely to the desired circular shape. To indicate the possible effects of the paraffin coating on the Sonoairduct tubing, a duct of the same dimensions and comprising 3 layers of paraffin-free cardboard was likewise formed.

The test consisted of applying a continuous flame to the inside surface of the duct, measuring the rapidity of flame spread and observing the extent of surface involvement. A 3-ft section of duct was inclined at a 20-degree angle with respect to the horizontal. A Tirrell burner (3/8 in. tip), in which the height of the flame with the burner vertical was adjusted to 5 in. with an inner cone 2 in. high, was mounted on a stand at a 45-degree angle with respect to the horizontal. The stand was placed so that the flame impinged at a 45-degree angle to the side of the inside wall and at a point 4 in. from the duct mouth. The point of application of the test flame, with the burner in test position, was 3 in. from the tip of the burner stem, measured along the axis of the burner stem. The flames followed a helical path to the top of the duct.

Using a gas heating value of 1090 Btu/ft^3, the average heat rate was 2905 Btu/hr. The gas flow to the burner was measured with a wet gas meter. The results of the three tests, run in the order shown, are given in Table 3, which includes calculated average values of flame spread based upon the time necessary for flames to extend the 36-in. length of duct.

Table 3 - Results of Flame-Spread Comparison Test

Test	Material	Time: 3-ft Flame Spread min:sec	Time: Total for Test min:sec	Flame-Spread Rate in/min	Gas Flow Rate ft^3/min	Heat Rate Btu/hr
a	Sonoairduct	5:10	6:20	7	0.0452	2950
b	Sal-Mo Duct Board	no spread	16:05	no spread	0.0444	2910
c	Cardboard	4:00	5:55	9	0.0437	2860

The Sal-Mo Asbestos Duct Board exhibited no flaming tendency during the entire length of the test and only a 1 3/4-in. by 3 1/2-in. white oval area surrounded by a blackened ring (corresponding to the areas of flame impingement and dispersement) was affected. The white area resulted from the non-flaming combustion of the black surface coating of the duct, whereas the larger surrounding ring retained the coating which was further blackened.

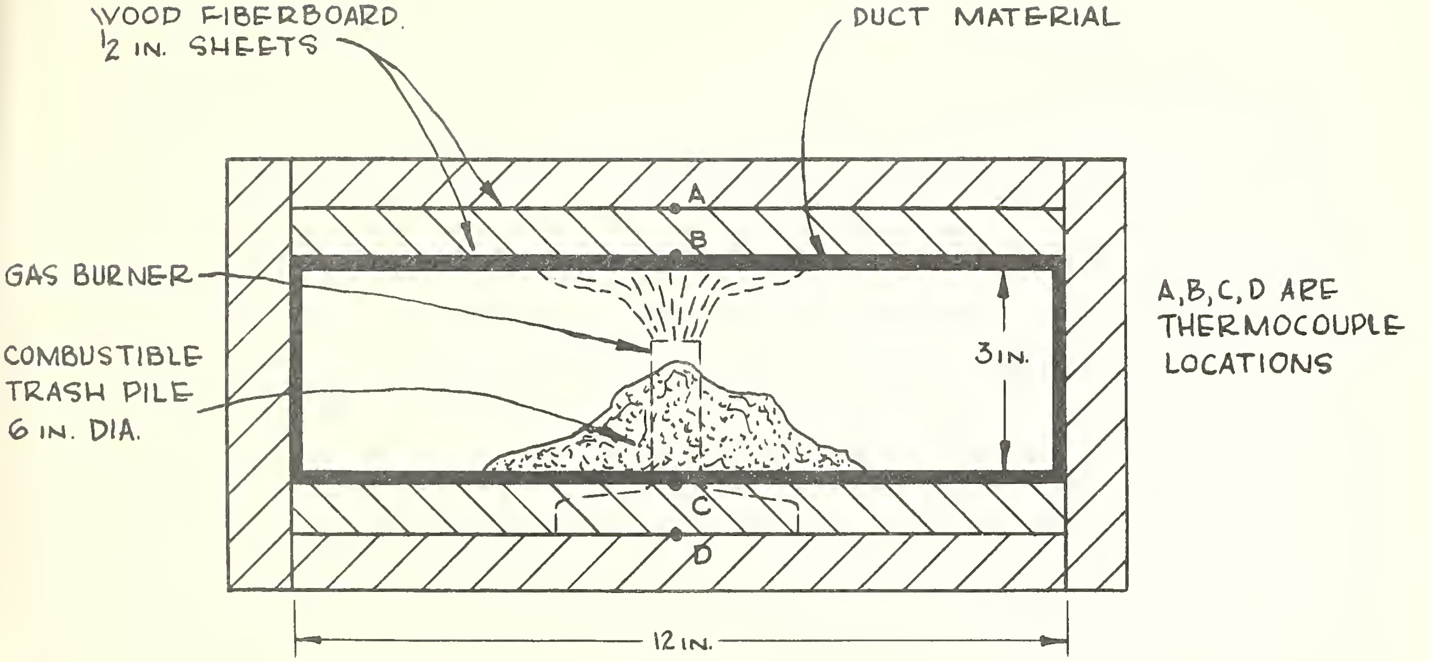
The Sonoairduct section propagated flames at an average rate of 7 in./min, yielding flames at the upper end after 5 min 10 sec, while the cardboard duct spread flames at an average rate of 9 in./min, yielding flames at the upper end after 4 min. The effect of the paraffin coating as indicated by this test was to decrease the flame-spread rate, but only slightly.

4. DISCUSSION AND CONCLUSIONS

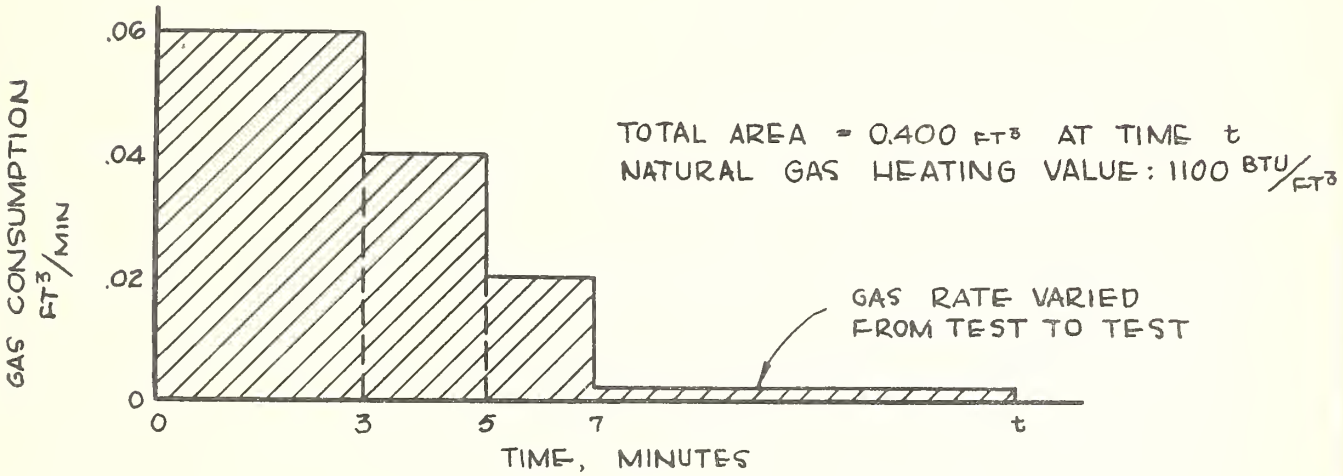
The above tests give information on those qualities which should be considered in developing criteria for self-heating, ignition, flame spread and combustibility. Whereas the testing procedures are by no means "standard," a number of the results obtained provide a basis for evaluation of substitute materials for metal ducts.

The flame-spread tests illustrated the ease with which a self-sustaining flame may be obtained, and the hazards associated with the ignition of a combustible duct. The conditions of test were not considered unlikely or impossible in general building construction, and the potential hazards might suggest or allow even more severe testing techniques. The tests gave convincing evidence that combustible ducts represent a distinct fire hazard.

The self-heating tests revealed that metals possess an inherent superiority over nonmetals with respect to the localized heat transmitted through a duct with combustible backing when the duct is subjected to a short-duration fire. The difference appeared to be due to metal buckling and separation resulting from thermal expansion. There appeared to be no difference between the Sal-Mo Asbestos Duct Board containing 16.5 percent combustible and asbestos millboard containing less than 3 percent combustible as evidenced by these tests.

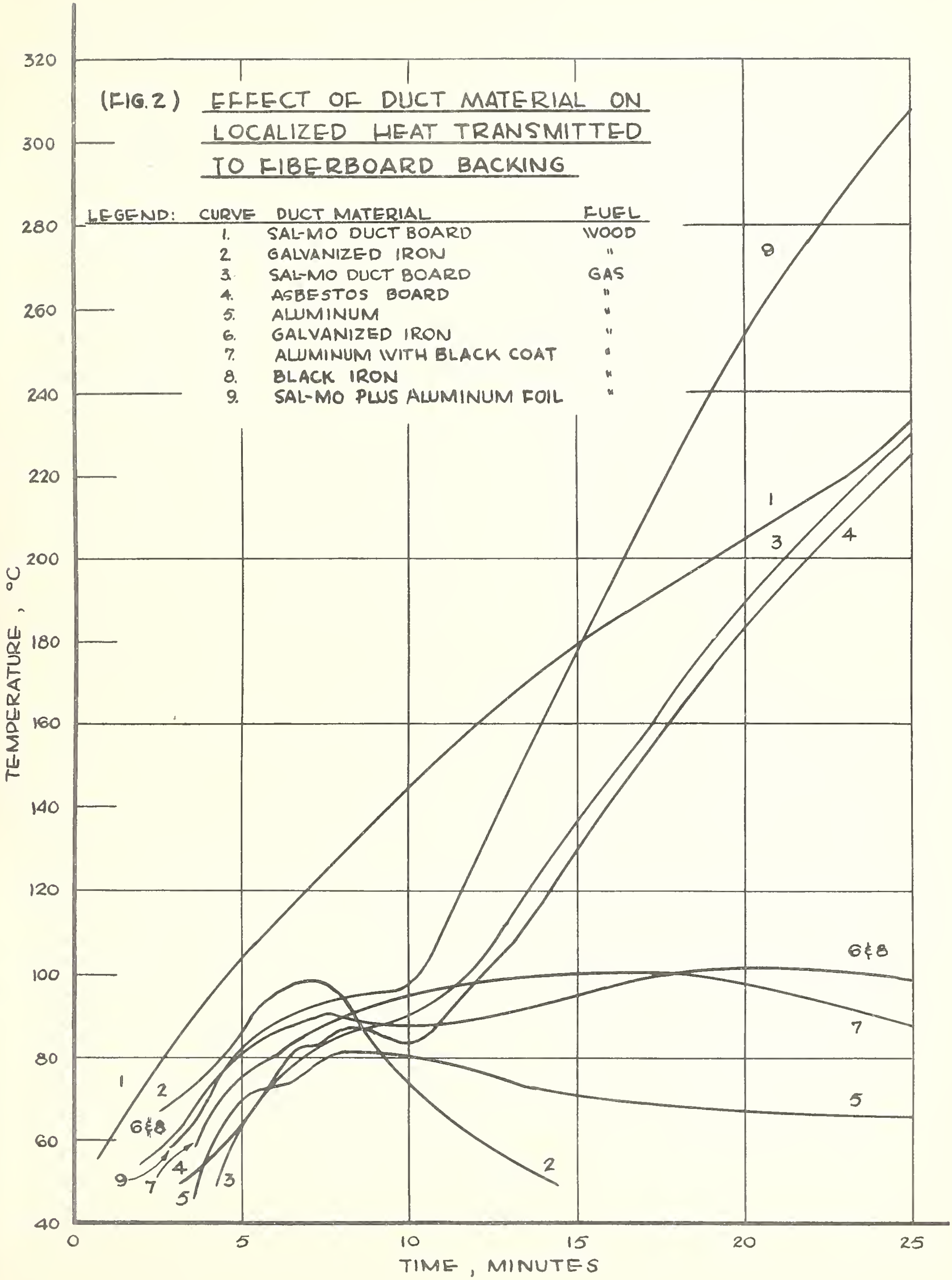


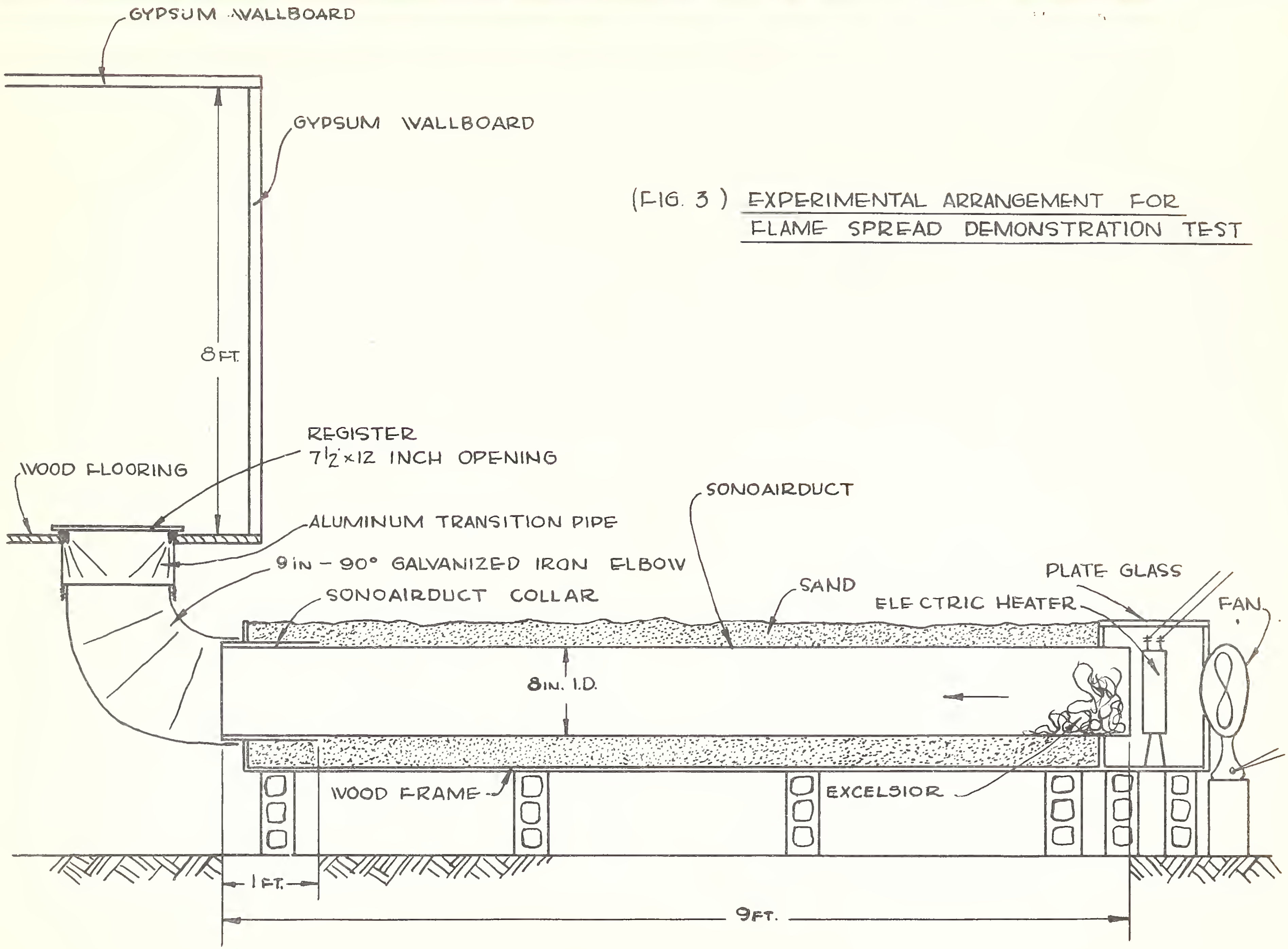
(A.) CROSS-SECTION OF 3×12 INCH DUCT COVERED WITH WOOD FIBERBOARD SHEETS, SHOWING COMBUSTIBLE TRASH PILE (SOLID) AND GAS BURNER (DASHED LINES) WHICH REPLACED IT.



(B.) "STANDARD" GAS RATE HISTORY

(FIG 1.) EXPERIMENTAL ARRANGEMENT FOR SELF-HEATING TEST


(FIG. 2) EFFECT OF DUCT MATERIAL ON LOCALIZED HEAT TRANSMITTED TO FIBERBOARD BACKING
LEGEND: CURVE DUCT MATERIAL FUEL
1. SAL-MO DUCT BOARD WOOD
2. GALVANIZED IRON "
3. SAL-MO DUCT BOARD GAS
4. ASBESTOS BOARD "
5. ALUMINUM "
6. GALVANIZED IRON "
7. ALUMINUM WITH BLACK COAT "
8. BLACK IRON "
9. SAL-MO PLUS ALUMINUM FOIL "
TEMPERATURE, °C
TIME, MINUTES
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
0
5
10
15
20
25
9
1
3
4
6&8
7
5
2
1
2
6&8
9
7
4
5
3



(FIG. 3) EXPERIMENTAL ARRANGEMENT FOR FLAME SPREAD DEMONSTRATION TEST

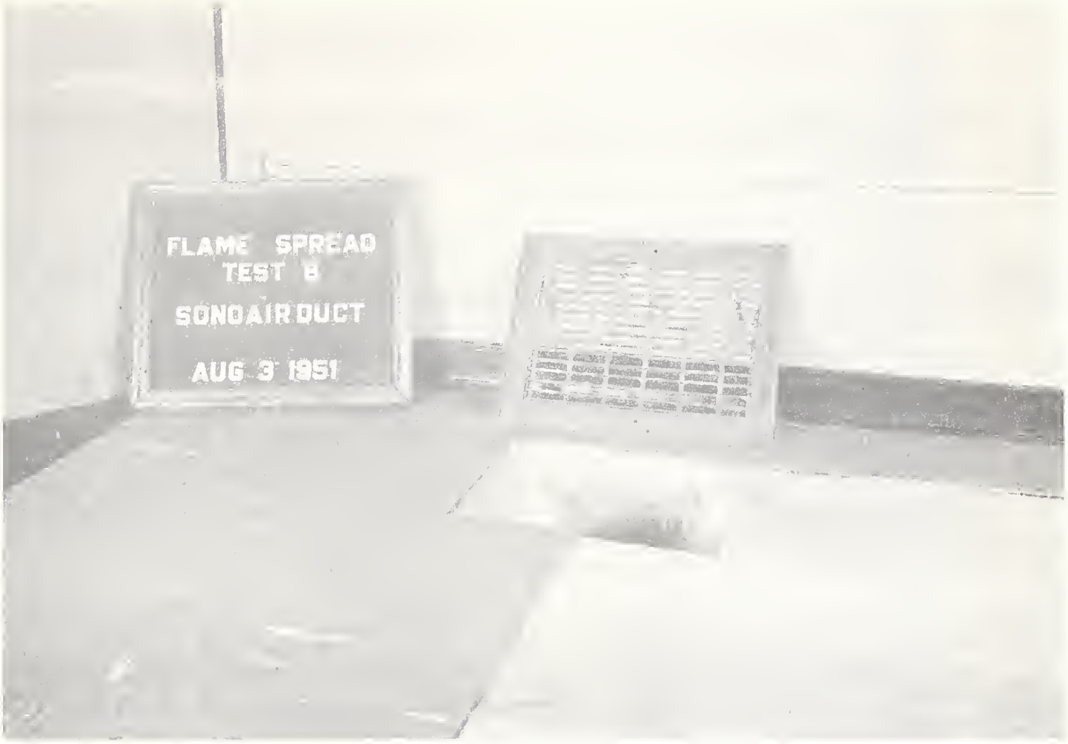


Fig. 4 Floor and register before test. Asphalt tile flooring partly laid to illustrate construction.

Fig. 5 Concrete-embedded duct before test showing heating chamber, fan and other details.

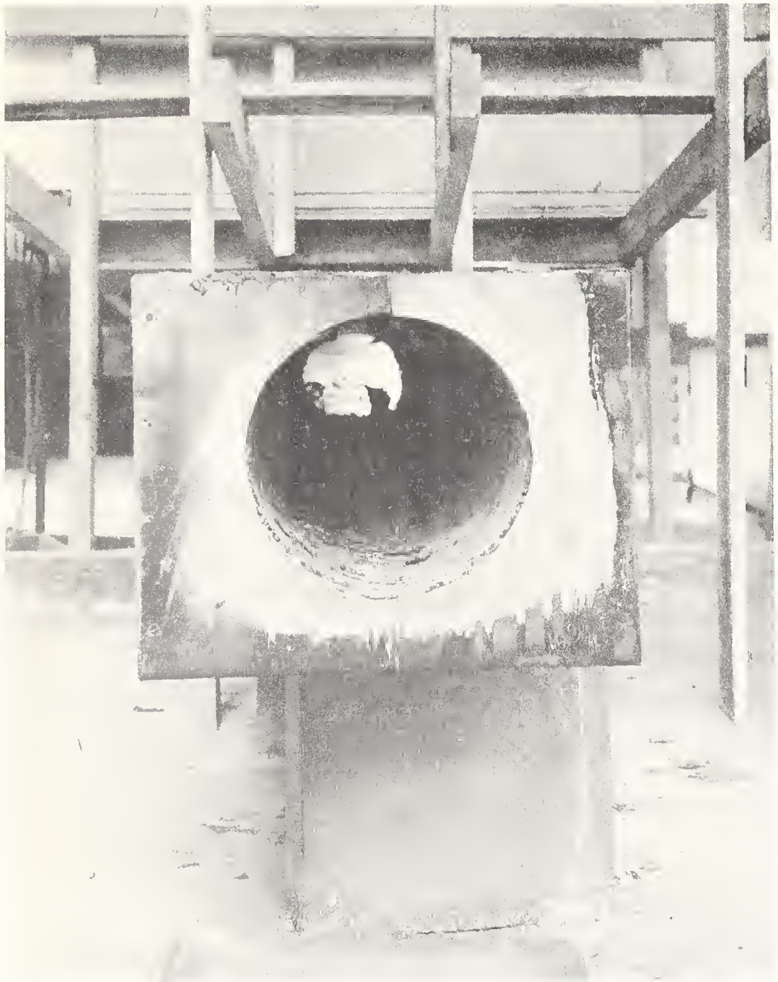


Fig. 6 Concrete duct casing after test. A few charred pieces of duct remain.

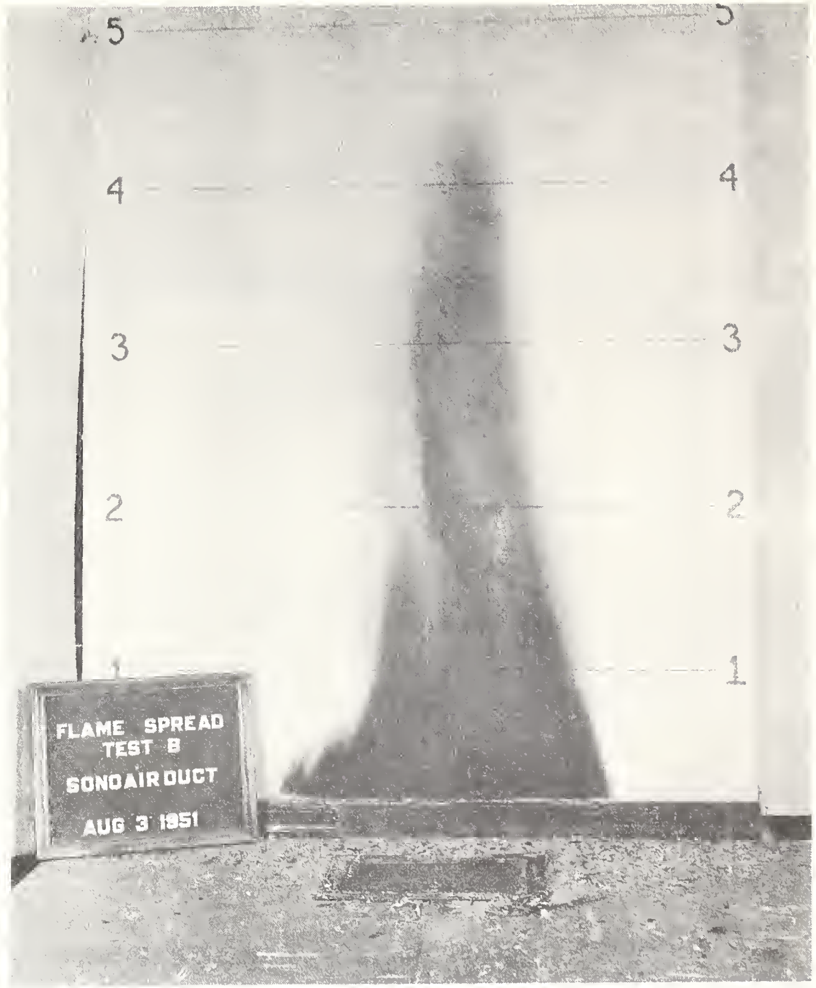
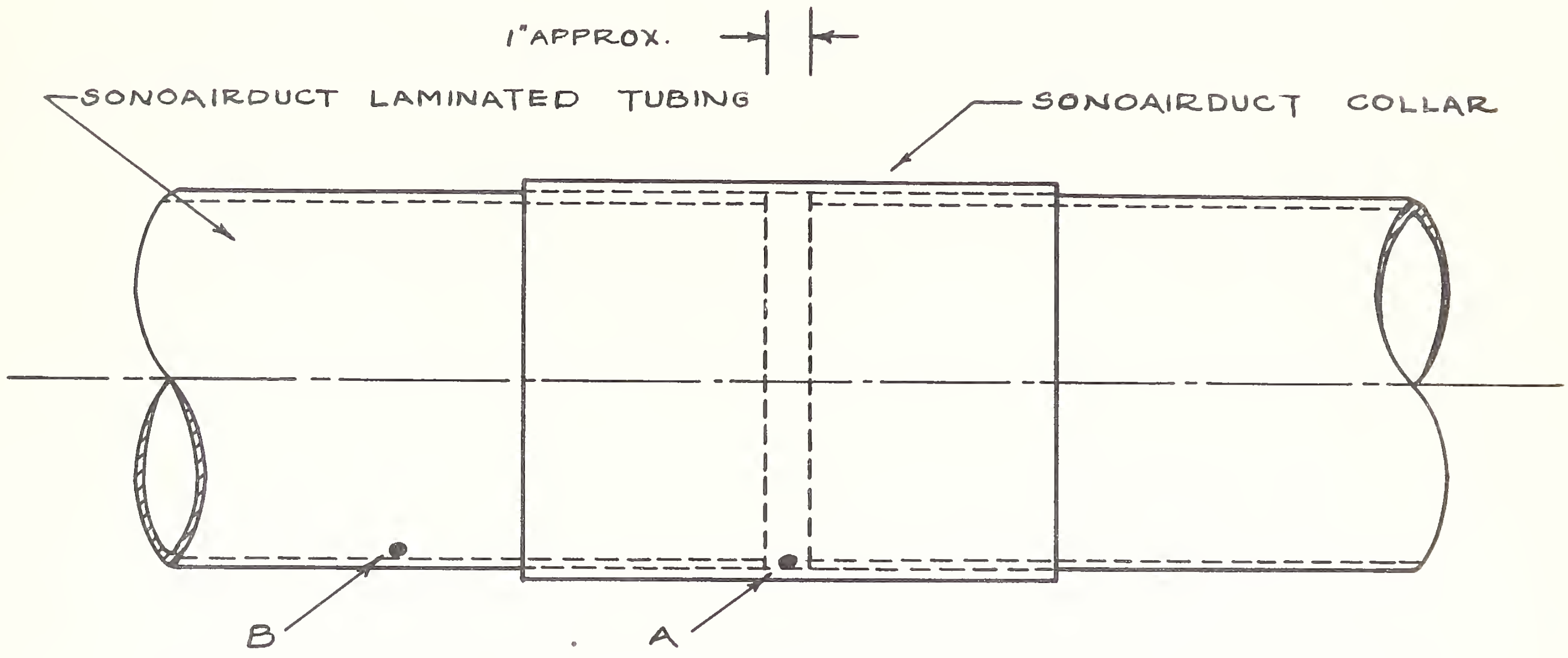


Fig. 7 Floor and plasterboard wall after test.



(FIG. 8) SKETCH OF DUCT SECTION - EASE OF IGNITION TEST

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The functions of the National Bureau of Standards are set forth in the Act of Congress, March 3, 1901, as amended by Congress in Public Law 619, 1950. These include the development and maintenance of the national standards of measurement and the provision of means and methods for making measurements consistent with these standards; the determination of physical constants and properties of materials; the development of methods and instruments for testing materials, devices, and structures; advisory services to Government Agencies on scientific and technical problems; invention and development of devices to serve special needs of the Government; and the development of standard practices, codes, and specifications. The work includes basic and applied research, development, engineering, instrumentation, testing, evaluation, calibration services and various consultation and information services. A major portion of the Bureau's work is performed for other Government Agencies, particularly the Department of Defense and the Atomic Energy Commission. The scope of activities is suggested by the listing of divisions and sections on the inside of the front cover.

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