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Development of An Ease of Ignition Test Using A Flame Exposure

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
Center for Fire Research
Washington, DC 20234

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NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

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Abstract

A test for the ease of ignition of interior finish materials by flame exposure was developed. Two specimens, 140 mm (5.5 in) wide by 152 mm (6 in) high, face each other at a distance of 53 mm (2.1 in) apart. A methane diffusion flame burns between these surfaces and extends to about 152 mm (6 in) above them. The operator observes the specimen surface and records the time-to-flame attachment. A phototube, which views the exposure flame, shows a marked increase in output when the specimens start contributing fuel. The ignition sensitivity is expressed by the time-to-flame attachment and by the time-to-fuel contribution. The times-to-flame attachment measured in the ignition apparatus generally ranked 22 materials with the observed times of wall involvement in full-scale tests. The results of this test may be useful as one factor in computer models of fire growth in enclosures.

Key Words: Building materials; fire tests; flame attachment; heat flux; ignition; room fires; wall coverings

1. INTRODUCTION

The history of fire research dates back to man's early attempts to understand fires which originated through natural events. The first ignition studies may have revolved around the observation that dead, dry grass and wood ignited easily whereas green, wet flora was difficult to ignite. As knowledge and use of fire increased, building laws (such as those in early Rome) reflected concern over the ignitability and combustibility of building materials. Crude tests were probably used to evaluate materials for use in certain types of construction. Somewhat more refined tests and observations are being made today.

The rate and extent of the fire buildup in an enclosure depends in part on the time to ignition, rate of flame spread, rate of heat release, potential heat, and thermal properties of the materials comprising the wall, ceiling, and floor surfaces and the furnishings. The flame spread rate of interior finish materials has traditionally been regulated through the building codes by the ASTM E 84 tunnel test [1][1]. For materials with low flame spread indexes (FSI), the tunnel rating is based to a large extent on the maximum distance of flame travel and to a lesser extent on when the specimen ignites or how rapidly the flame spreads. However, a room lined with a low-density foamed plastic having

[1] Figures in brackets indicate literature references at the end of this paper.

a FSI of 25 can become fully involved and reach flashover[2] in an extremely short time with a rather modest ignition source [2], even though the contribution to fire spread of any interior finish material with a FSI of 25 or less has been considered relatively low.

This anomaly is due in part to the short time to ignition and the rapid flame spread rate along low density combustible materials. Although their short time of ignition and rapid flame spread are readily observed during a tunnel test, these attributes have generally not been reflected in a high FSI. The new method of calculating the FSI, adopted in 1977, based on the area under the distance versus time curve, still falls short of reflecting the potentially severe fire hazard due to rapid ignition of low density combustible materials.

Several test procedures have been proposed to measure the ignitability of materials. These tests use different types and levels of fire exposure, different specimen sizes and orientations, and varying criteria for determining ignition. The exposures may include external radiation, flame contact, hot air, or some combination of these. The ignition may be piloted or unpiloted; it may be transient or sustained; it may be glowing or flaming. The ignitability may be reported in terms of the temperature of the surface at the time of ignition, the minimum incident heat flux required to produce ignition, or the time required for a prescribed evidence of ignition under a standard exposure. The choice

[2] Flashover is defined as the time at which thermal radiation levels have become high enough to ignite light combustibles on the floor. This occurs as approximately 25 kW/m^2.

of test conditions usually depends on the fire scenario of concern. There is no universal ignition test that is applicable to all situations, nor should there be. A proposed ISO (International Organization for Standardization) ignitability test uses a radiant exposure of a horizontally mounted specimen with an intermittent pilot and reports the time to ignition at five flux levels [3]. By extrapolating these data along the best-fit straight line, a "minimum exposure level for ignition" is determined. ASTM D 1929, an ignition test for plastics, uses a hot air exposure and records the minimum temperature of the air surrounding the surface which will cause piloted and unpiloted ignition of the gases within the enclosing furnace [4]. The ease of ignition test described in this report measures the time-to-ignition of a vertical surface exposed to a flame with thermal radiation reinforcement from a facing specimen. Materials which ignite rapidly and spread flame quickly have short ignition times in this apparatus. The time-to-ignition of a combustible material depends upon the time required to heat its surface to the pyrolysis temperature. This time is an increasing function of the thermal inertia, i.e., the square root of the product of the thermal conductivity, density, and heat capacity.

This ignition test was designed primarily for evaluating interior finish materials located on walls and ceilings. During the development of a compartment fire, flame contact from a burning item (wastebasket, chair, etc.) may occur on these surfaces. The vertical orientation of the specimens in the test is a direct simulation of the more common wall exposure situation. It also is expected to provide relative ignition

times for ceiling (horizontal facing down) configurations, although the flame exposure of the walls and ceilings will be somewhat different. The apparatus does not simulate the fire exposure for flooring materials.

The times between the initiation of the exposure flame and (a) a flame attachment to the specimen surface and (b) the contribution of fuel, or volatile pyrolysis products, to the exposure flame are determined. The test is intended to compare the ease of ignition of different interior finish materials and to supply necessary input data on ignition to computer models which will be used to predict the fire growth in rooms with combustible walls or ceilings. This information, combined with a material's heat release rate, flame spread rate, potential heat, and thermal properties can be used to provide a more realistic assessment of its potential contribution to a room fire. However, this test is not intended to serve as a general flammability or combustibility test but rather to provide specific information on the ignitibility of a material.

This report provides (1) a discussion of the parametric effects related to the test procedure, (2) ignition test results which illustrate how the test method discriminates between the ignition sensitivity of a variety of building materials and (3) validation of the test against results obtained from full-scale fire tests.

2. TEST PARAMETERS

2.1 Specimen Size

The width and height of the specimen, 140 x 152 mm (5.5 x 6 in), was selected to provide a representative sample of the material that could easily be used in a bench test. The thickness was chosen to be that at which the material is normally used because it is expected that the thickness might influence the time to ignition. Tests were conducted to evaluate the adequacy of the specimen height. Four materials were chosen to study the effect of the specimen height on the time to flame attachment: 4-mm (5/32-in) prefinished plywood, 6-mm (1/4-in) hardboard, 13-mm (1/2-in) wood fiber ceiling board, and 16-mm (5/8-in) type-X gypsum board. Because of the limited supply of materials, three tests were conducted with 140 x 300-mm (5.5 x 12-in) specimens for each of the materials. Test data for two of the 152-mm (6-in) high specimens, 4-mm (5/32-in) prefinished plywood and the 6-mm (1/4-in) hardboard, were taken from the series of tests exhibited in Table 5. The 13-mm (1/2-in) wood fiber ceiling board and 16-mm (5/8-in) Type X gypsum board specimens do not represent the same materials as those listed in Table 5. The average flame attachment times for the two specimen sizes, shown in Table 1, display only slight differences. Statistical t-tests conducted on each set of specimen data indicate that there is 95 percent confidence that the specimen size had no affect on the time to flame attachment. The size of the specimens was, therefore, set at 140 x 152 mm (5.5 x 6 in).

2.2 Specimen Conditioning

The purpose of conditioning is to ensure that all specimens are evaluated under comparable conditions which are appropriate for a particular study [5]. The fire behavior of some materials will vary markedly with their moisture content which can vary greatly depending upon the relative humidity. Lee, Loftus, and Gross [6] showed that the moisture content has a strong effect on the surface flammability of cellulosic materials.

During the early developmental period of the ease of ignition test method, a study was conducted by Parker, Brackett, Willard, and Zile on the effect of humidity on the ignition of some typical room finishing materials [7]. The first condition tested was 23°C (73°F) at 50 percent relative humidity for 17 days; the second was one day in a forced hot air oven at 60°C (140°F), and the third was six days in the 60°C (140°F) oven. The last condition was sufficient to drive off 6.8 percent by weight of water and cause a reduction of 50 percent in the time to ignition of wood fiberboard. Substantial reductions in the ignition times of other cellulosic materials were also observed.

Data for 20 mm (25/32 in) solid red oak taken with the present apparatus are shown in table 2. It is important that a standard conditioning procedure is adopted for comparative purposes. It is recommended that these conditions be predrying at 60°C (140°F) for 24 hours followed

by reaching weight equilibrium at 23 ± 3°C at a relative humidity of 50 ± 5 percent. The specimens should be conditioned in this environment until they reach a rate of weight change of less than 0.1 percent per day.

2.3 Spacing Between Specimens

During the early development of the ease of ignition test apparatus, the specimens were positioned with a 22-mm (0.88-in) space between them. The flame between the specimens was relatively laminar. The flame impinged across the entire surface of both test specimens. While conducting tests on a wide range of materials, it became apparent that the specimen spacing was too close. It was found that the spacing did not provide room for the expansion of materials treated with intumescent finishes. By increasing the distance between the specimens to 50-mm (2.1-in), the required space for expansion was provided. The increased distance between the specimens provided a more desirable exposure flame. It was more luminous and turbulent and no longer impinged constantly on the specimen's surface. The exposure was more like that of diffusion flames produced by incipient burning of furnishings and building materials in a typical room fire.

2.4 Ventilation

An overall view of the test chamber is shown in figure 1. The chamber is designed with two openings, one on each side, near its bottom,

as noted in figure 2. These openings allow the air required for combustion of the gas and the specimen to be drawn in by means of convective currents that develop during the test. This air flow also helps to cool the test chamber. A detailed description of the chamber is contained in appendix A. The area of the table between and below the face of the two specimens is cut away leaving a sharp edged opening so that combustion air can be drawn up by free convection. Combustion air is also entrained along the vertical openings between the specimens. An opening in the top allows the heated air and products of combustion to flow into a chemical hood where they are removed from the test area. The air requirement for combustion will vary with the type of specimen and its heat release rate. For typical materials which would be tested in this apparatus, 98 kJ (93 BTU) of heat are produced when all of the oxygen is consumed in 0.028 m^3 (1 ft^3) of air. The maximum heat release rates are expected to be approximately 200 kW/m^2 although the specimens would usually be extinguished before this value is reached. The area of the two specimens is 426 cm^2 (66 in^2), so that the total rate of heat production from the specimens would be 8.5 kW (485 BTU/min). The air requirement would be 2.5 L/s (5.2 ft^3/min) for the specimens. It takes 10 volumes of air to burn one volume of methane. The total gas flow to the igniting flame is 0.2 L/s (0.42 ft^3/min); therefore, the air requirement is 2.0 L/s (4.2 ft^3/min) for the igniting flame. The total air requirement for combustion would be 4.5 L/s (9.4 ft^3/min) assuming that the specimens were allowed to reach their peak burning rate with the igniting flame on. The air flow rate through the chamber, as measured with a hot wire anemometer at the inlet air openings, during a

test is approximately 15.5 L/s (33 ft^3/min), which is about three times the air required for combustion. This rate is primarily controlled by the convective currents created in the test chamber, but it will be influenced by the amount of draft provided by the chemical hood. Therefore, the air flow through the hood should be maintained at a level that will adequately remove the products of combustion without affecting the air flow through the ignition test chamber.

2.5 Cooling Blocks

Water-cooled brass blocks were incorporated into the test apparatus to (1) maintain the specimen assembly exposed to the flame at a relatively constant temperature during extended periods of use in order to reduce variations in temperature and radiation that could result in changing test conditions, and (2) reduce the chances of burn injury to test operators accidentally contacting the hot test frame.

2.6 Gas Supply

2.6.1 Type of Gas

Initially, the gas used for the exposure flame in the ease of ignition apparatus was typical city gas (consisting principally of methane plus small amounts of other components) which is used for home and industrial heating in the Washington, DC area. City gas varies considerably in different geographical areas of the country. The

heating value can vary from 22.3 to 37.2 MJ/m^3 (600 to 1000 BTU/ft^3). Since these variations may have a significant influence on the properties of the exposure flame it was decided to consider the use of bottled CP methane, for the ease of ignition test. A series of experiments was conducted to compare the flame and exposure characteristics of CP methane and the city gas used in Washington, D.C.

The flame temperature and total incident heat flux on the specimen's surface were measured. CP methane, which is 99.0 percent pure, provides a gross heating value of 37.7 MJ/m^3 (1012 BTU/ft^3) at 15.5°C, 101 Pa (60°F, 29.92 in Hg). Since the city gas pressure at the ease of ignition test apparatus is 320 mm H_2O (12.5 in H_2O) and the tank pressure of CP methane is 15.6 MPa (2265 psig), a regulator system was used to reduce the CP methane gas pressure to the working pressure of the ignition apparatus. The gross heating value of city gas used in these experiments was measured to be 37.5 MJ/m^3 (1009 BTU/ft^3).

A 0.127-mm (5-mil) chromel-alumel thermocouple was used for the determination of the apparent flame temperature. Measurements were recorded along the central vertical plane of the exposure flame. The thermocouple was placed midway between the specimens at three locations: one at the bottom edge, one at the center, and one at the top edge of the specimens. The average flame temperature for the city gas was 671°C (1240°F) and for CP methane it was 666°C (1230°F), a reduction of less than 1 percent. The temperature distribution along this central plane can be seen in table 3.

The total incident heat flux was measured with a copper disk calorimeter located in the right specimen test frame. (See figure 3 and also description of calorimeter in appendix B.) A series of six tests was conducted with gas flow rate of 0.20 L/s (25 SCFH) for city gas and for CP methane. The results shown in table 4 indicate that there was no difference between city gas and CP methane in this experiment.

Further review of the various grades of methane gas shows that Technical Grade methane, 98.0 percent pure with a heating value of 37.7 MJ/m^3 (1012 BTU/ft^3), is approximately equivalent to CP methane in quality but costs substantially less. With the desire to reduce costs while providing the consistent gas quality required for making comparative measurements of specimens within a laboratory and between different laboratories, Technical Grade methane was used as the primary fuel for the ease of ignition test.

2.6.2 Incident Heat Flux versus Gas Flow Rate

Tests were conducted to evaluate the effects of gas flow rate on the total incident heat flux to a specimen surface. The heat flux was measured at six different gas flow rates ranging from 0.1 to 0.3 L/s (13 to 39 CFH). As seen in figure 4, the heat flux was 47 kW/m^2 at the highest gas flow rate.

2.6.3 Flame Attachment Time versus Total Heat Flux

This test method was designed to evaluate the ignition sensitivity of building materials in contact with flames from incidental or low energy fires. A typical example is a wastebasket or funiture fire adjacent to a wall. In the case of fires in the corners of a room or in narrow spaces between walls and furniture, there can be an appreciable exchange of heat between the exposed surfaces. A study by Gross and Fang at NBS [8] with wastebasket fires showed that the maximum incident heat flux at the edge of the flame could be as high as 53 kW/m^2 (4.6 BTU/ft^2sec) depending on the size and type of wastebasket, fuel load, and fuel burning rate. On the basis of these experiments, the average heat flux of 32 kW/m^2 (2.8 BTU/ft^2sec) was selected. This was obtained with a combined gas flow rate from both burners of approximately 0.2 L/s (25 CFH) with CP methane. The heat flux into the specimens was not distributed evenly across the surface. Heat flux measurements, with specimen spacing at 50 mm (2.1 in) and an average heat flux of 32 kW/m^2 (2.8 BTU/ft^2sec), showed a variation of 24 percent over the 75 mm (3 in) span between the lower and upper copper disks of the calorimeter used for calibrating the apparatus. (See appendix B for a detailed description of the copper disk calorimeter.) The higher heat flux, 36 kW/m^2 (3.1 BTU/ft^2sec), was obtained from the lower copper disk; and the lower heat flux, 29 kW/m^2 (2.5 BTU/ft^2sec), was obtained from the top disk.

Tests were conducted to evaluate the effects of changes in total incident heat flux on the flame attachment times on 13 mm (1/2 in) wood fiber ceiling board as seen in Figure 5. The incident heat flux was measured with the copper disk calorimeter. Tests were performed with gas flow rates of 0.140, 0.220, and 0.275 L/s (18, 28, and 35 CFH).

3. IGNITION CRITERIA

3.1 Flame Attachment

The ignition sequence begins with the flame exposure of the specimen. As the surface temperature approaches 100°C (212°F) free moisture near the surface is evaporated. As the surface dries and continues to rise in temperature, surface degradation begins. Degradation is most often recognized as the discoloration of the surface associated with charring. With some materials, bubbling of the surface, swelling, shrinkage, and/or cracking may be experienced before charring occurs. These conditions, as well as any unusual observations, are reported with the test data. Smoke generally is produced when surface degradation begins. As the specimen continues to heat, volatiles are emitted at an increasing rate until they are either ignited or the specimen is completely depleted. When the mass flow rate of volatiles per unit area reaches some threshold value, they are ignited by the exposure flame. With some materials a thin, transient, transparent flame is seen above the specimen's surface just before flame attachment is observed. However, the test operator, by direct observation of the specimen's surface,

records the flame attachment time only when a flame becomes fixed to a point on the specimen's surface. The attached flame is generally characterized as being opaque and slightly brighter than the gas exposure flame. In some cases, rather than spreading across the surface, the flame will only attach at small, isolated areas and, thus, provide very little fuel to the exposure flame. On the other hand, high velocity streams of volatiles issuing from cracks developed in the specimen surface will sometimes provide a significant amount of fuel to the flame before a flame attachment is observed.

3.2 Fuel Contribution

The problem of describing ignition using a single definition related only to flame attachment became apparent while conducting tests on low density foam insulation materials. As can be seen in table 5, these materials provide a significant fuel contribution before flame attachment is achieved. This results from the fact that large quantities of high velocity combustible vapors are released from the specimen, and burning takes place away from the specimen's surface. A series of experiments was conducted with thermocouples and phototubes to determine the best method for recording the initiation of this fuel contribution. A single thermocouple located at different points between the specimens and a thermocouple grid located in the exposure flame above them were used to measure the temperature rise when the specimens begin to release fuel. Phototubes were also positioned at different locations inside the test chamber. The results of these experiments showed that thermocouples

had excessive noise due to flame fluctuations. The phototubes also produced noise, but at a much lower level due to the averaging effect of viewing a large flame area. By placing additional capacitance into the phototube circuit, the high frequency noise was reduced to an acceptable level. Also, to insure that the phototube output was showing a definite increase in luminosity of the flame above that which might be caused by longer period fluctuations, the time of fuel contribution was picked from a point on the phototube output curve 25 percent above the base line obtained with noncombustible ceramic specimens. A phototube record showing the determination of the time to fuel contribution is presented in figure 11. The type 922 phototube was selected because it has an S-1 surface, which has a good response to near-infrared radiation emitted by the combustion products. (Since this work was completed, experiments with a row of thermocouples just above the top edge of the specimen and a small distance out from the surface may give even more reproducible results than the phototube.)

The time to fuel contribution is basically controlled by the amount of combustible volatiles available and the thermal properties of the material. With wood and other cellulosic building materials, flame attachment usually occurs before the time when a significant quantity of fuel is contributed to the exposure flame. Therefore, the time to fuel contribution can occur before or after flame attachment. However, it may not occur at all with materials which release small quantities of combustible volatiles.

4. IGNITION DATA ON MATERIALS

Ignition tests were conducted on a variety of materials, some of which were painted and others which were treated with flame retardant chemicals. The results can be seen in table 5. The variation in fuel contribution times with several materials is illustrated on a linear time line in figure 6. In general, the fuel contribution time for a cellulosic product is seen to increase with density. The time to ignition depends on (1) the thermophysical properties, particularly the product of the thermal conductivity, density, and specific heat, (2) the thermochemical properties, and (3) the surface properties, particularly the absorptivity, which determine the radiation heat transfer and the surface roughness which affects the convective heating and the effective area. Coatings alter the surface properties and, in some cases, provide a thin layer of much higher or lower heat of combustion than the substrate material. The coating may also contain flame inhibitors which are released into the gas phase. In the case of intumescent coatings, the thermophysical properties of the expanded coating are also important in limiting heat transfer to the substrate. The effect of surface coatings on lauan plywood can be seen in table 5 where selected intumescent coatings increased the ignition times by a factor of five.

5. COMPARISON WITH FULL-SCALE TESTS

Perhaps the best single index of the fire hazard of a room would be the time required to reach flashover once a significant fire developed.

Rapid fire buildup can occur as a result of the contribution of combustible interior finish materials. A possible scenario, in this case, would be the ignition of a newspaper on an upholstered chair. After an initiation period the fire might build up to the point of flame impingement on the wall. After some ignition delay time that could be determined by the ease of ignition test, the wall would start contributing fuel, and flames would spread at a rate depending on the thermal properties of the wall material and its heat release rate. Since the time to ignition also depends on the thermal inertia (square root of the product of the thermal conductivity, density, and specific heat) data from the ease of ignition test, and the heat release rate test should provide some indication of the time required for a room lined with this material to reach flashover.

In order to demonstrate the usefulness of the ease of ignition test as one of the indicators of the performance of an interior finish material in a room fire, the time to flame attachment recorded in the test is compared in table 6 and figure 7 with the time of wall ignition in several full-scale room fire tests series carried out at NBS and at Underwriters Laboratories (UL). These tests include the corner room test series conducted by Fang [9], the mobile home tests conducted by Budnick [10,11], and the full-scale room fire tests conducted at UL [2]. The included tests were limited to those using wood cribs as an ignition source; tests in which upholstered chairs were the ignition source had too much scatter and were not included. Even with this limitation, considerable variations are experienced in the full-scale fire tests.

Part of the spread in the data is due to fire growth variations in the wood cribs and part is due to the difficulty of accurately determining the exact time of wall involvement in the full-scale tests. One other variation that influences the results presented in table 6 and figure 7 is that the ease of ignition test submits specimens to a relatively constant exposure, while in a typical fire environment incident heat flux is constantly changing.

It should also be noted that results would probably be somewhat different if the materials were tested using a heat flux other than 32 kW/m^2 (2.8 BTU/ft^2sec). However, it is important to remember that the heat flux exposure chosen for this test is based on research by Gross and Fang [8] on low intensity fires which are often associated with initial fire growth in rooms. Figure 7 shows the data compared to a 45 degree line which has been adjusted to allow for a 30-second delay in crib fire buildup. Taking the average wall ignition delay times for a given material and allowing for the inherent delay time required for the fire to buildup in the wood crib, figure 7 shows that the ease of ignition test can provide a reasonable estimate of the ignition delay time of the wall lining material exposed to a wood crib or similar furnishing fire.

Table 7 shows a comparison of the fuel contribution times in the ease of ignition test with the times of wall involvement and flameover in the full-scale room fire tests with the 9.1-kg (20-lb) cribs at UL [2]. The peak heat release rates measured in the NBS heat release

calorimeter at an incident flux of 30 kW/m^2 are also included. The times, listed in this table, at which flame movement beyond 1.4 m (4.5 ft) was first reported in the tunnel provide an approximate measure of the time to fuel contribution for another incident flux and specimen orientation.

Although a limited number of tests were run, the range of materials and results illustrates the usefulness of the ease of ignition test. Flames extended beyond the doorway much earlier with the foam plastic materials A and S than with the plywood material H, as would be expected from the ease of ignition test results even though the flame spread classification (FSC) and the heat release rate were much lower for the plastics than for the plywood. The time differences are more dramatic if the fire buildup time in the crib is taken into account. However, the ease of ignition test results alone suggest that G and H would flashover about the same time. While the ease of ignition test provides an indication of the thermal inertia of the material which is one determining factor in the flame spread, the other factor is the heat release rate which is very low for material G.

Material R has a low thermal inertia but its fuel production rate through the foil face is insufficient to establish a flaming ignition. Its heat release rate is also very low so that full flame involvement was not observed in the room test. The exposure was large enough in the region of the burner of the tunnel to burn through the foil and induce a flaming ignition at 20 seconds. Although this also occurred in the region

of the wood crib in the room test, the exposure outside this region was insufficient to destroy the integrity of the foil and propagate the flame. It is important to consider the heat release rate as well as the time to fuel contribution.

6. PRECISION AND ACCURACY

As with other tests, operator skills and good laboratory techniques are required for obtaining the most accurate results and maintaining good repeatability in relation to the observation and recording of flame attachment time and for properly determining the time to fuel contribution from the chart record.

It is known that natural and manufactured products are not always uniform. Materials generally contain many imperfections, such as inconsistency in density and quantitative and qualitative changes in chemical composition. For example, wood changes density near knots and with annual growth. Chemical changes are also associated with these physical variations. Manufactured products also reflect irregularities even under closely controlled process conditions. Some of these may result from variations in raw materials properties, feed problems, equipment, and human failures. The result of the above variations may influence the ignition sensitivity of the material.

To demonstrate the precision of the test procedure with a relatively uniform material, twelve tests were conducted on the standard hardboard used for calibrating the ASTM E 162 "Test for Surface Flammability of Materials Using a Radiant Heat Energy Source" (see table 8). The results show relatively good repeatability. The mean average for the time of flame attachment was 109 seconds and time of fuel contribution was 138 seconds. The time of flame attachment exhibits a repeatability coefficient of variation of 4.0 percent while the time of fuel contribution has a repeatability coefficient of variation 3.7 percent. With materials that are not as uniform as the standard hardboard it can be expected that the variations will be larger. Coefficients of variations for two materials listed in table 5 demonstrate the increased variation. A 4-mm (5/32-in) prefinished lauan plywood specimen has coefficients of variation for flame attachment time of 8.1 percent and fuel contribution time of 8.2 percent. Another lauan plywood with a fire retardant vinyl surface exhibits a repeatability coefficient of variation for flame attachment time of 12 percent and for fuel contribution time of 8.6 percent.

7. SUMMARY

An ease of ignition test using a flame exposure has been developed which can be used to evaluate the ignition sensitivity of a wide range of interior finish materials. The specimen configuration and gas flame simulates the type of diffusion flame exposure which is experienced by a wall surface when an item of furniture is burning in the corner of a

room. The incident heat flux imposed in the test exposure is 32 kW/m^2 based on the experiments of Gross and Fang [8], but it can be varied from 20 to 45 kW/m^2 by changing the burner gas flow rate. A minimum of four tests are conducted to obtain an average time to fuel contribution and time of flame attachment to the surface. The time to fuel contribution is defined as the time when the recorded output of the phototube viewing the exposure flame is increased by 25 percent above the base line (another method of determining the time to fuel contribution using thermocouples is being investigated). The time to flame attachment is determined by direct observation of the surface.

This test method allows for a good view of the specimen's surface during the test. Observations during tests are recorded because they can provide additional insight as to the ignitability of a material during a room fire.

The comparison of the time to flame attachment and the reported times of ignition of the wall materials in 22 full-scale room fire tests with a wide variety of interior finish materials and test configurations indicates a reasonable agreement between the ease of ignition test with the exposure given above and full-scale room fire tests although there is a large amount of scatter. The difficulty in estimating the involvement times of the wall as well as variations in the buildup of the ignition sources in the room were probably responsible for a large part of the observed data spread.

As can be seen in table 5, there are large ranges in the flame attachment and fuel contribution times of typical interior finish materials. Since the ignition of interior finish materials often results from exposures to similar fire environments, the times to ignition measured in this test may be used to predict their time of involvement in a room fire and to rank them accordingly.

This test is not intended to serve as a general flammability or combustibility test but is designed to provide information on the ignitability of a material which, when combined with its heat release rate, flame spread rate, potential heat, and thermal properties, can be used to provide a more realistic assessment of its potential hazard in a room fire.

In particular, one should not expect a correlation between the time to ignition by this test and the flame spread classification which depends on other attributes of the material. Materials which have short ignition times and rapid flame spread rates due to their low thermal inertia do not necessarily have high flame spread classifications in the E 84 tunnel test nor do they necessarily have high heat release rates.

8. ACKNOWLEDGMENT

We are indebted to Mr. Roland Willard who fabricated most of the test apparatus.

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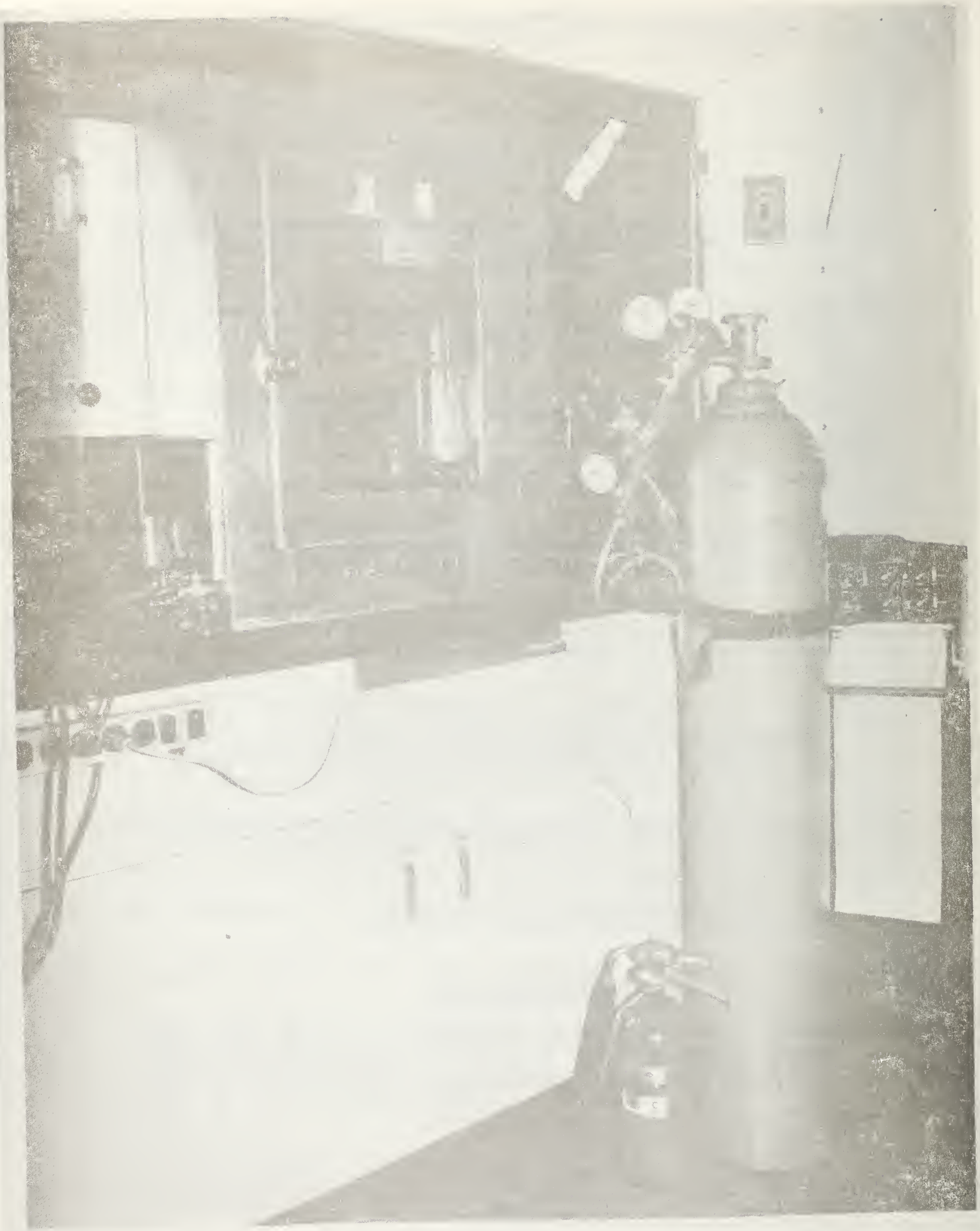
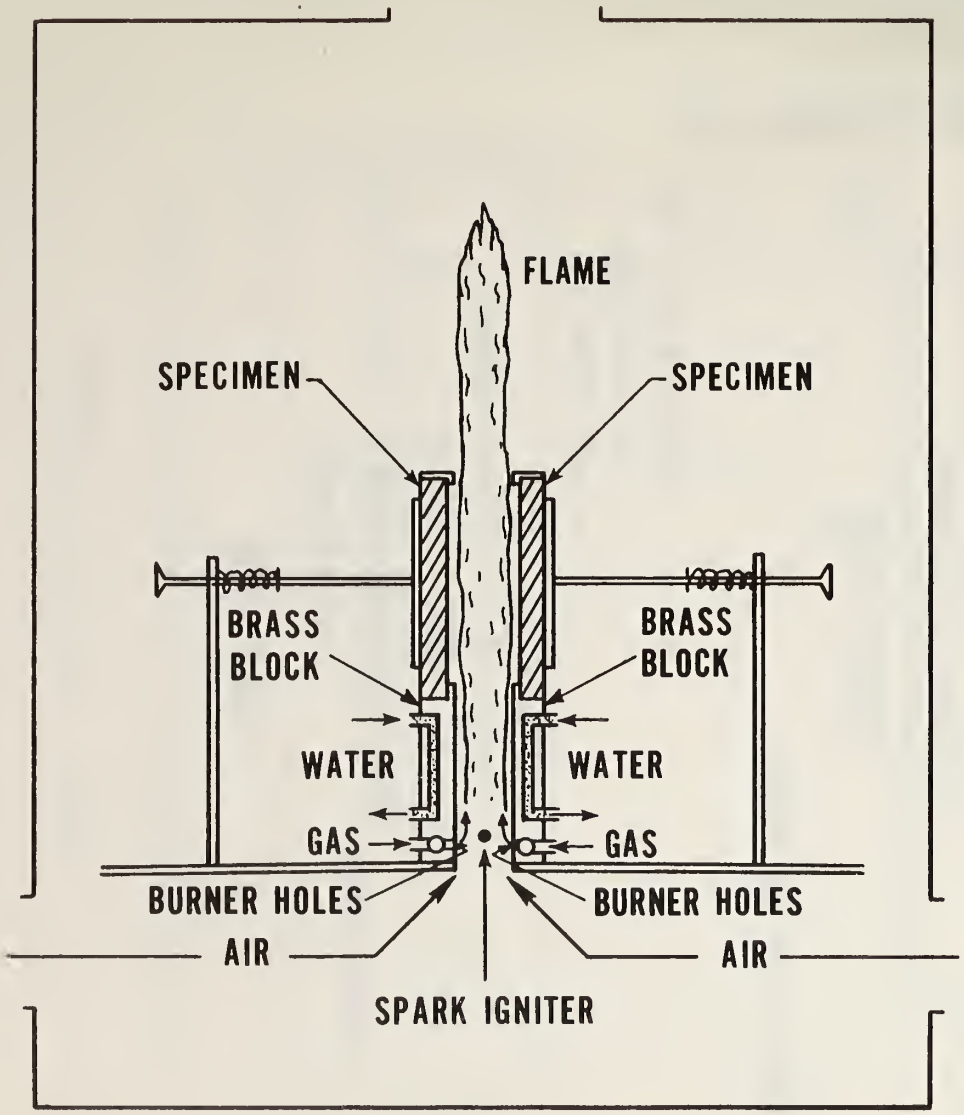


Figure 1. Photograph of Ignition Test Apparatus



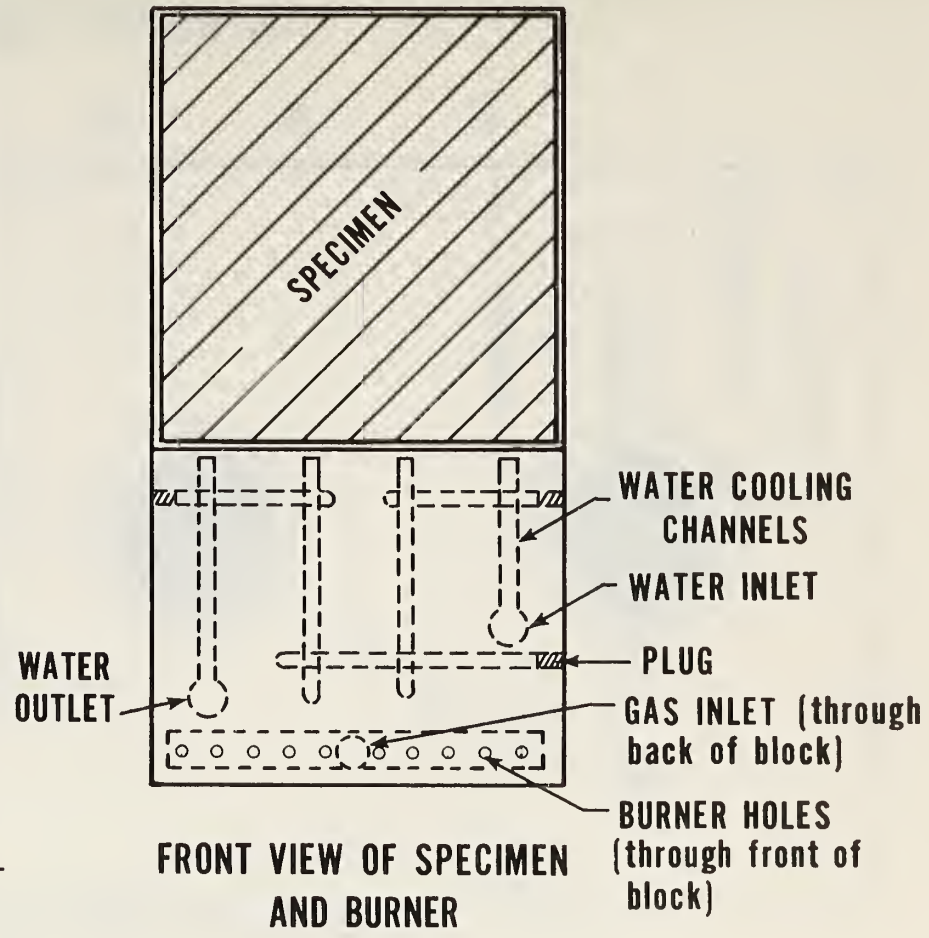


Figure 2. Sketch of Ignition Apparatus

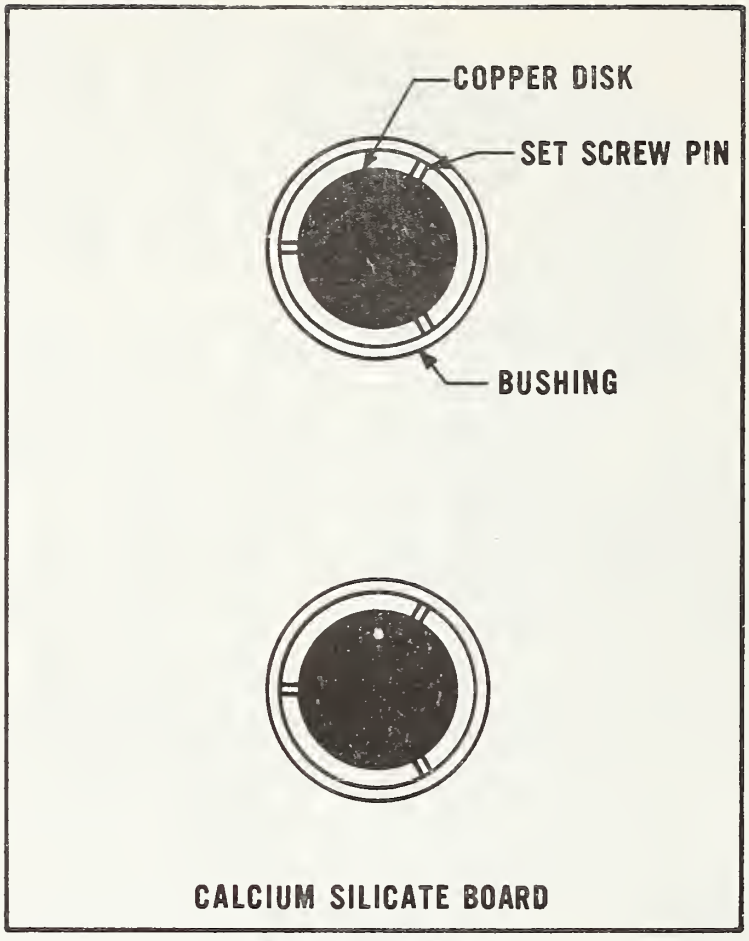


Figure 3. Copper Disk Calorimeter

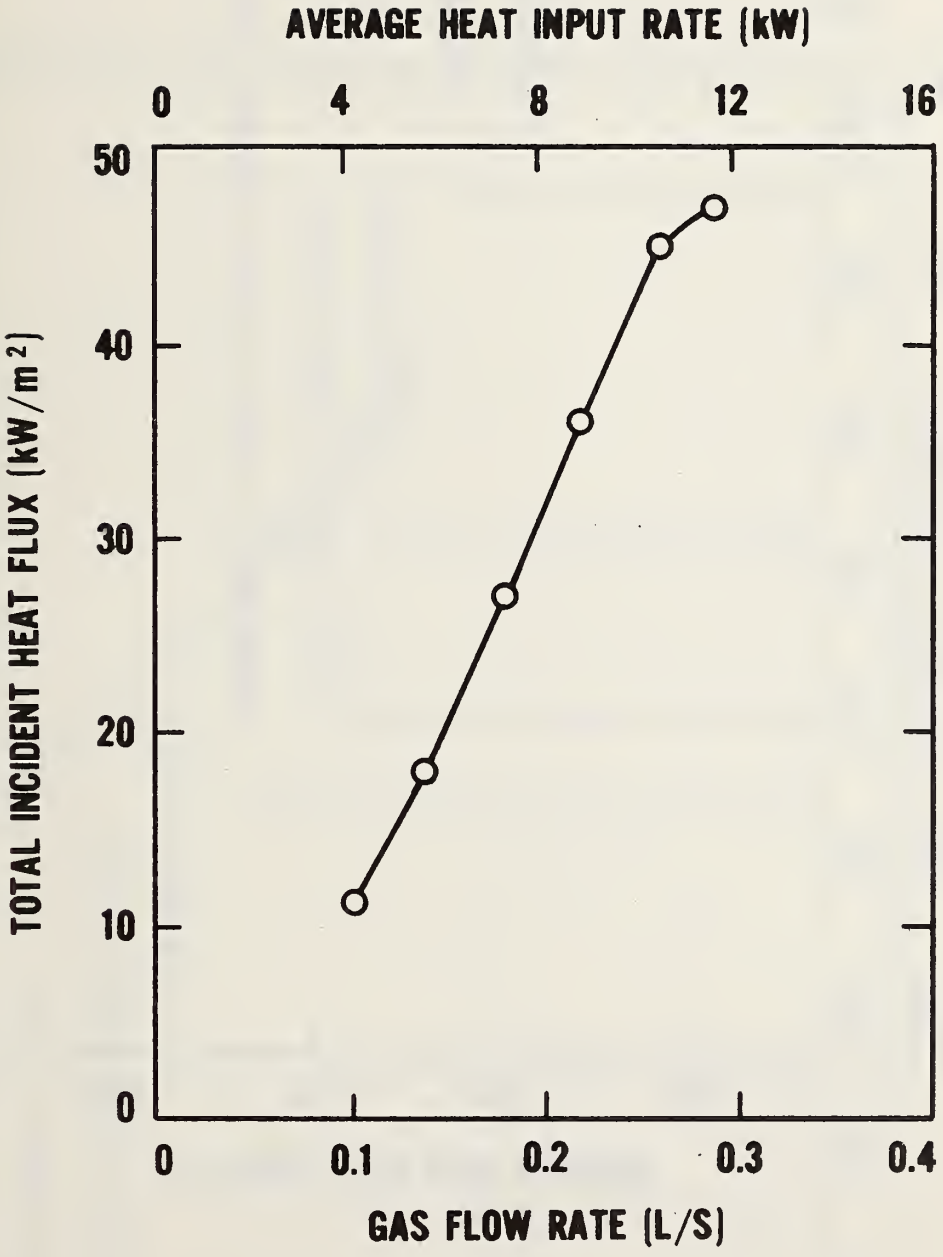


Figure 4. Total Incident Heat Flux versus Gas Flow Rate

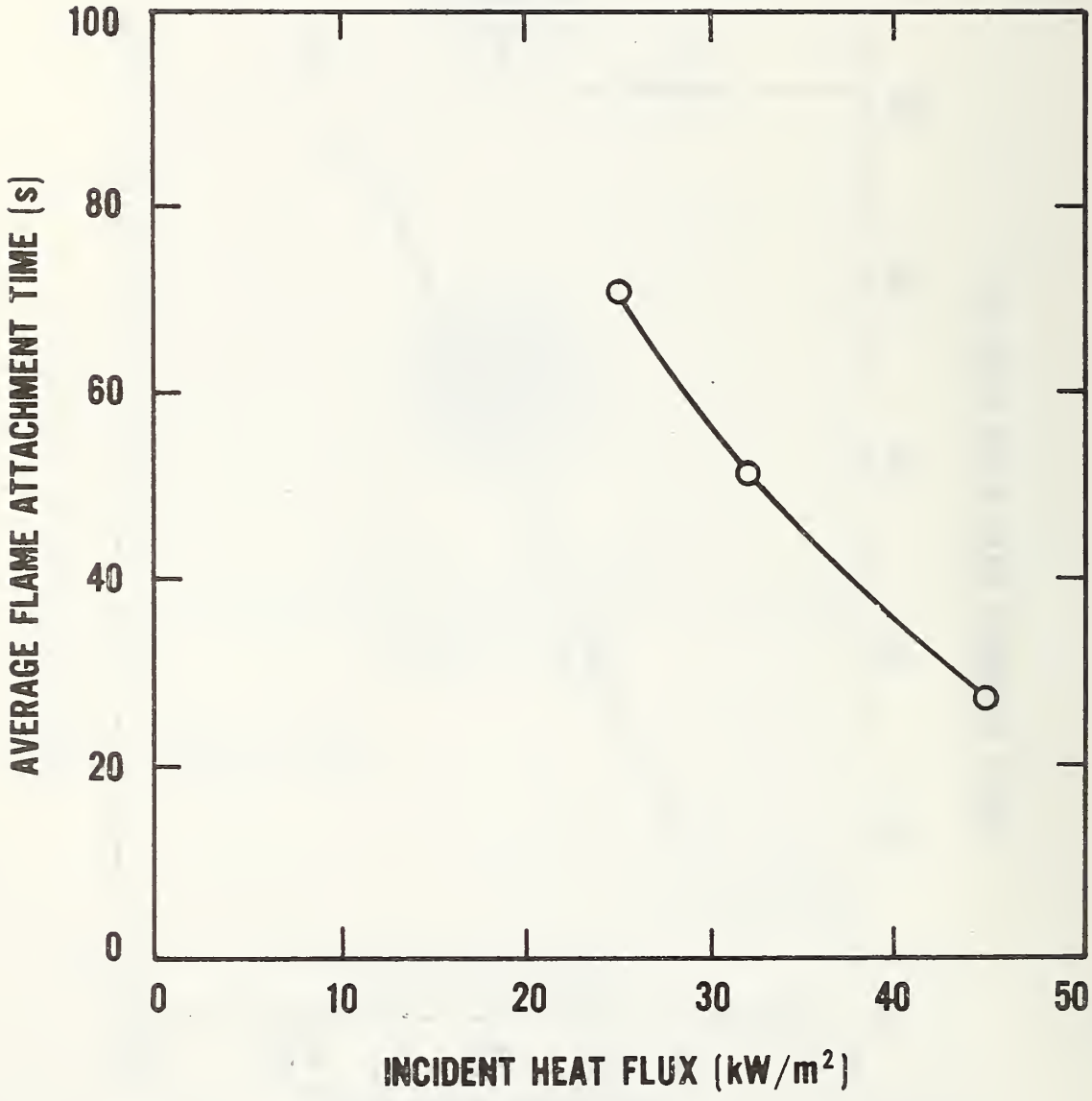


Figure 5. Incident Heat Flux vs. Time to Flame Attachment for Wood Fiber Ceiling Board

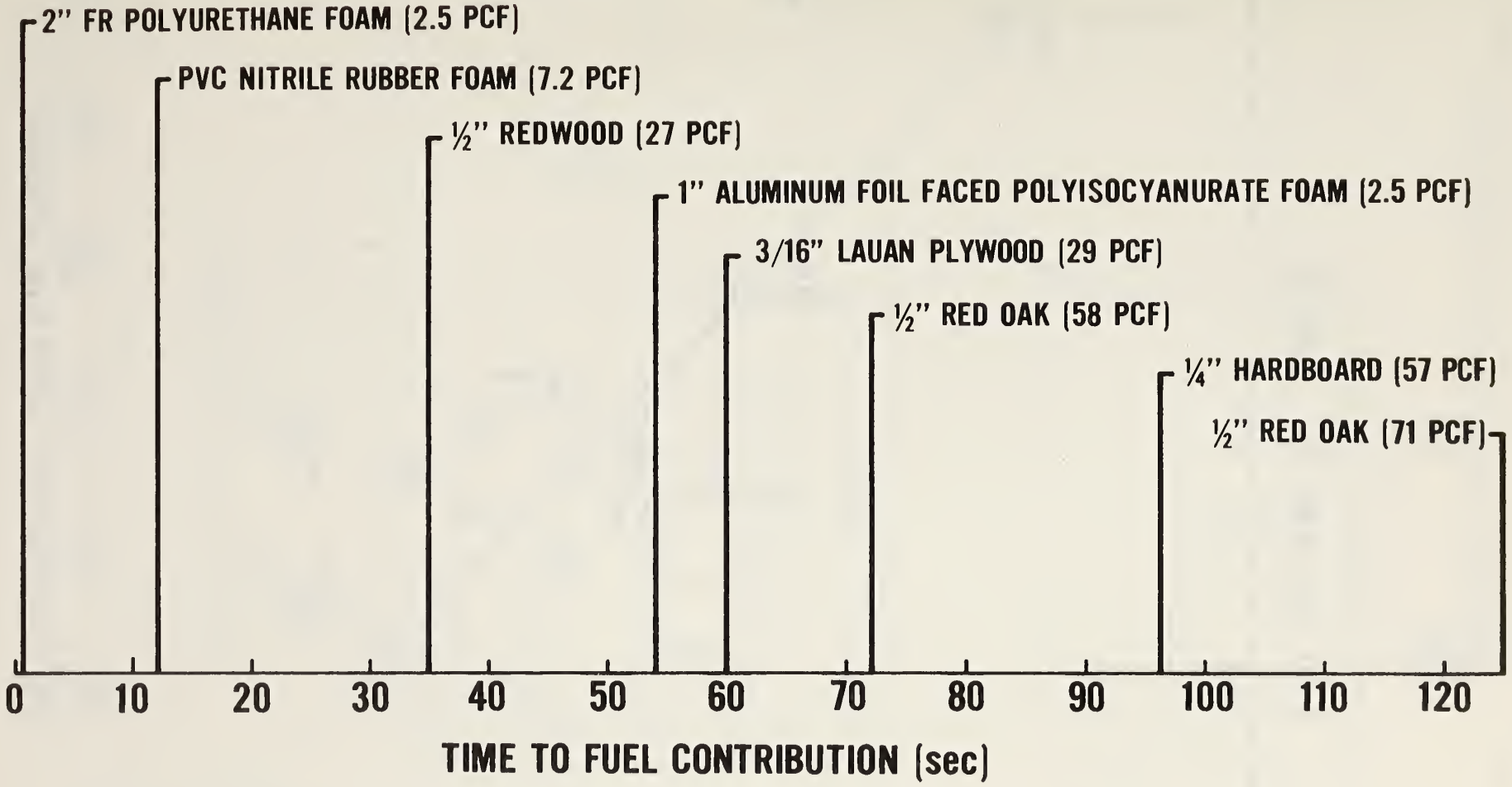
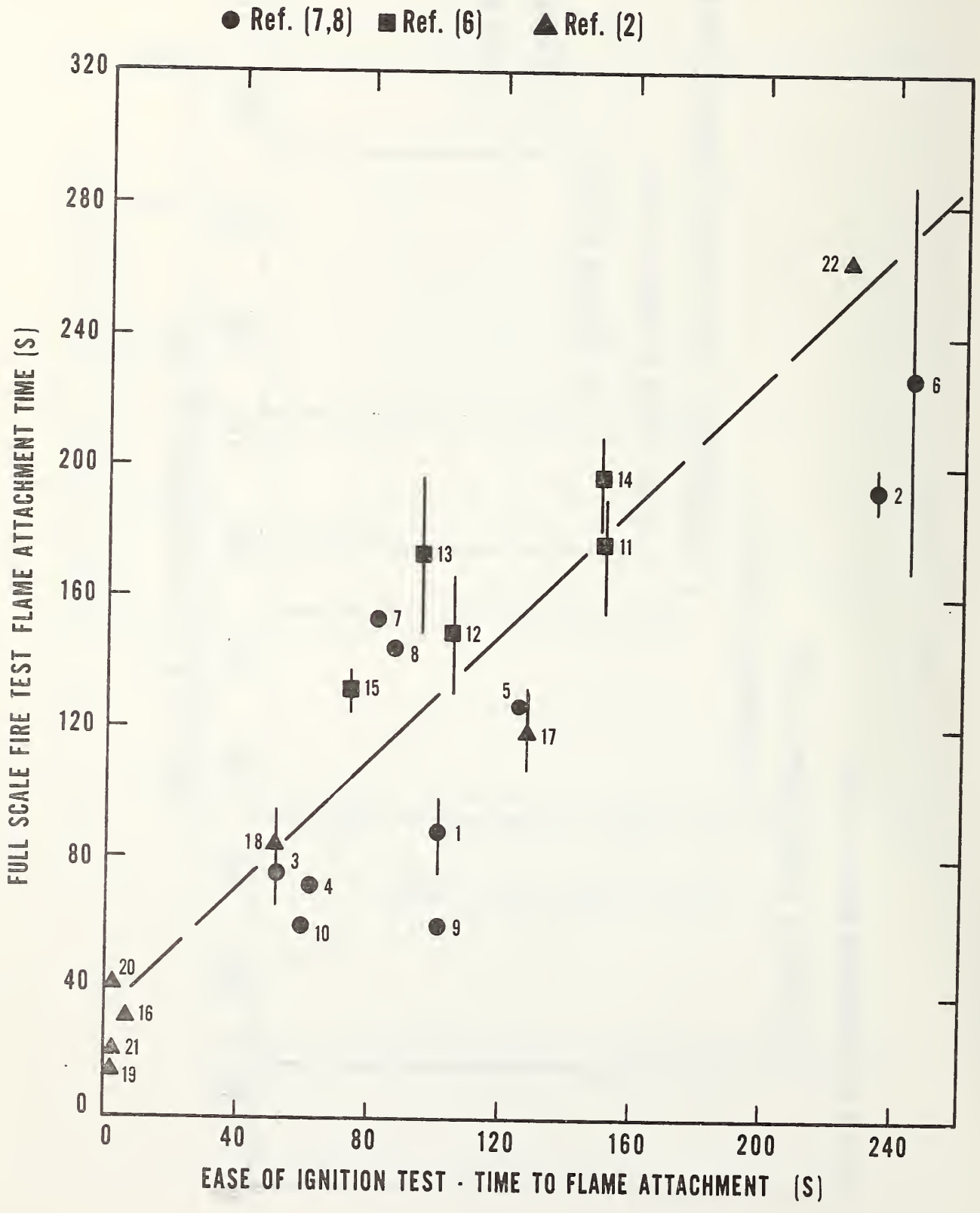


Figure 6. Fuel Contribution Times for a Variety of Materials

Figure 7. Flame Attachment Times in Full Scale Tests Versus Flame Attachment Times in the Fase of Ignition Test



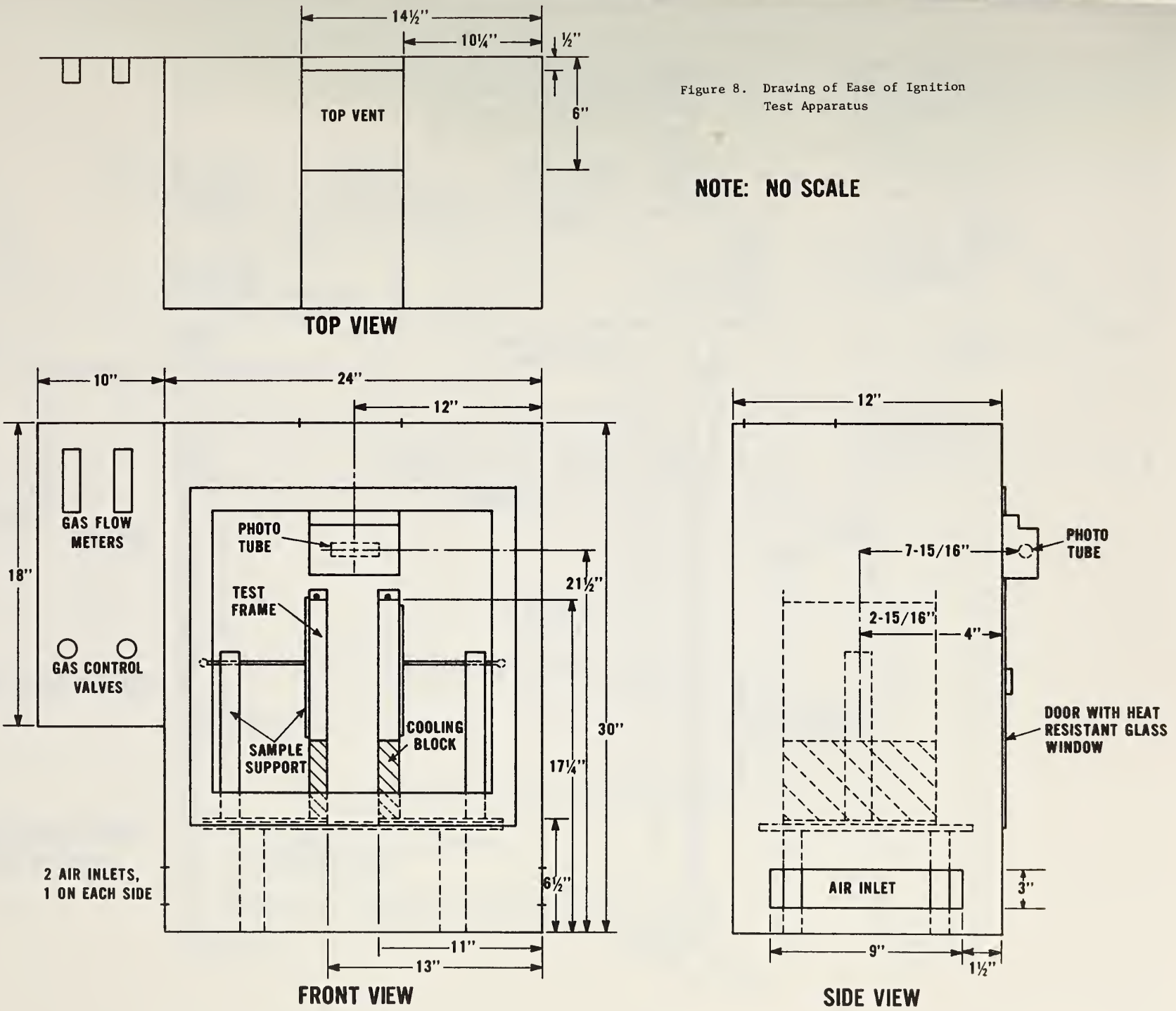
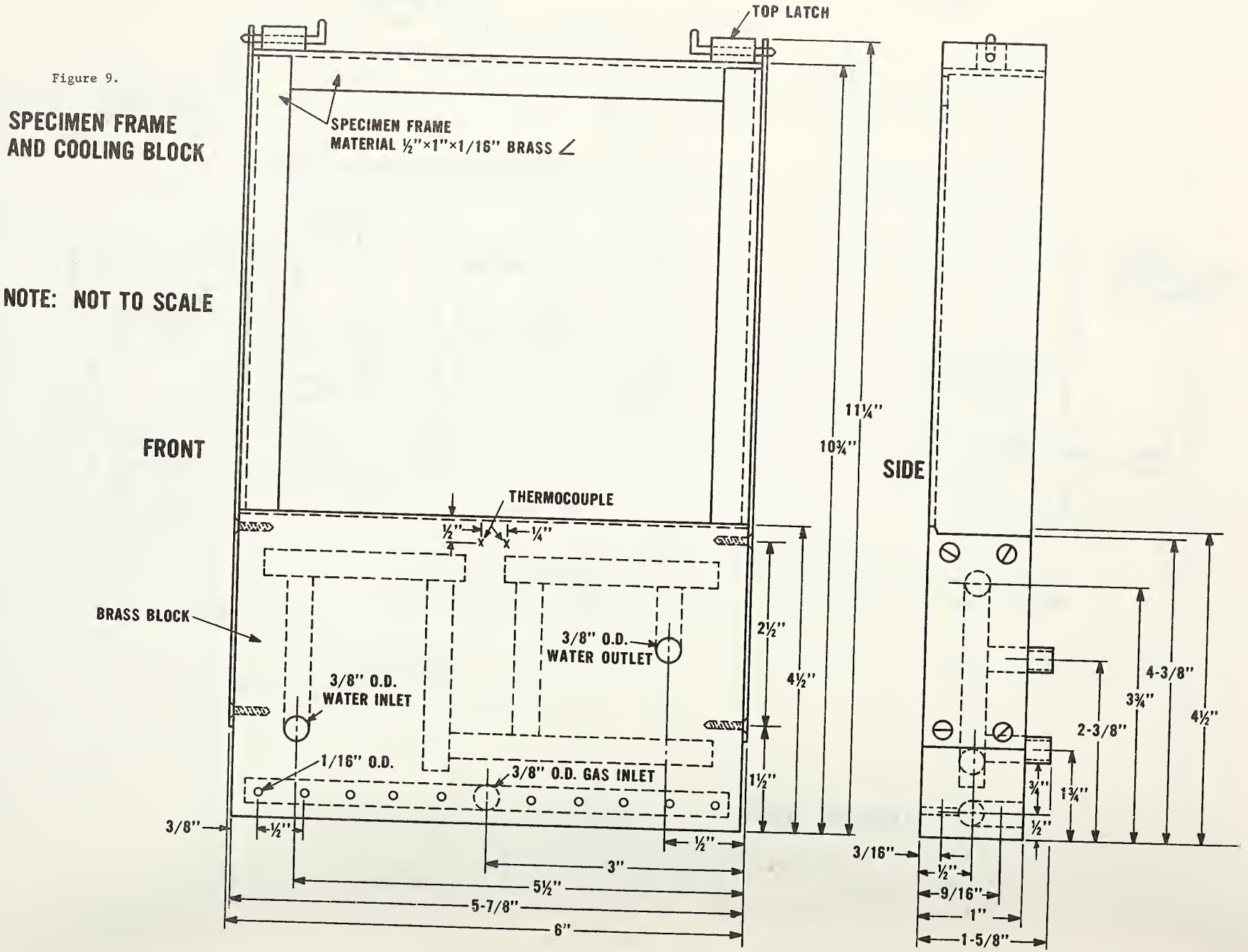


Figure 8. Drawing of Ease of Ignition Test Apparatus

NOTE: NO SCALE

Figure 9.


SPECIMEN FRAME AND COOLING BLOCK
NOTE: NOT TO SCALE
FRONT
SIDE
TOP LATCH
SPECIMEN FRAME
MATERIAL ½"×1"×1/16" BRASS ∠
THERMOCOUPLE
½"
¼"
BRASS BLOCK
3/8" O.D.
WATER OUTLET
3/8" O.D.
WATER INLET
1/16" O.D.
3/8" O.D. GAS INLET
11¼"
10¾"
2½"
4½"
1½"
3/8"
½"
3"
5½"
5-7/8"
6"
3/16"
½"
9/16"
1"
1-5/8"
4-3/8"
3¾"
2-3/8"
4½"
¾"
1¾"
½"

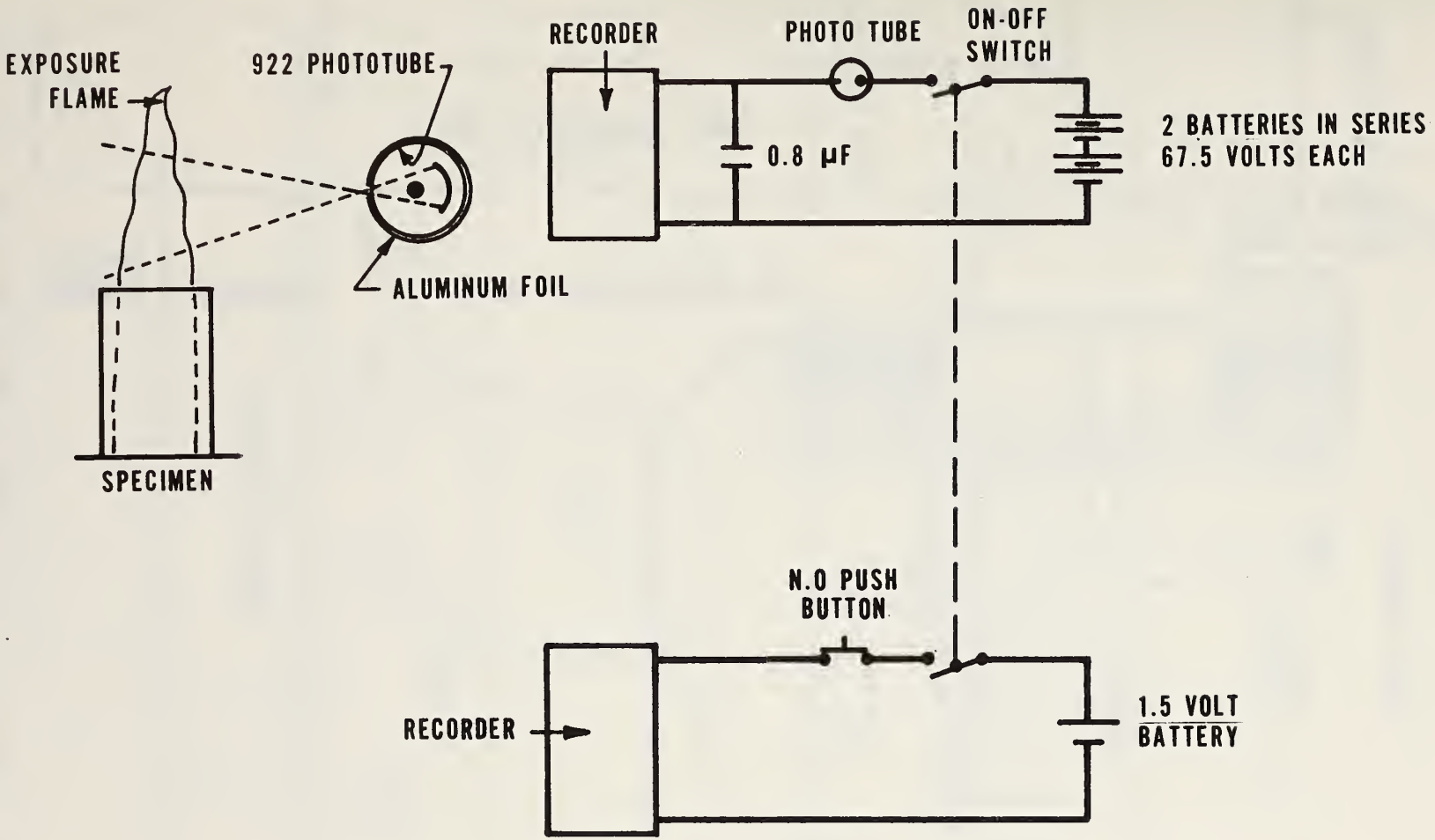


Figure 10. Phototube and Time Marker Circuits

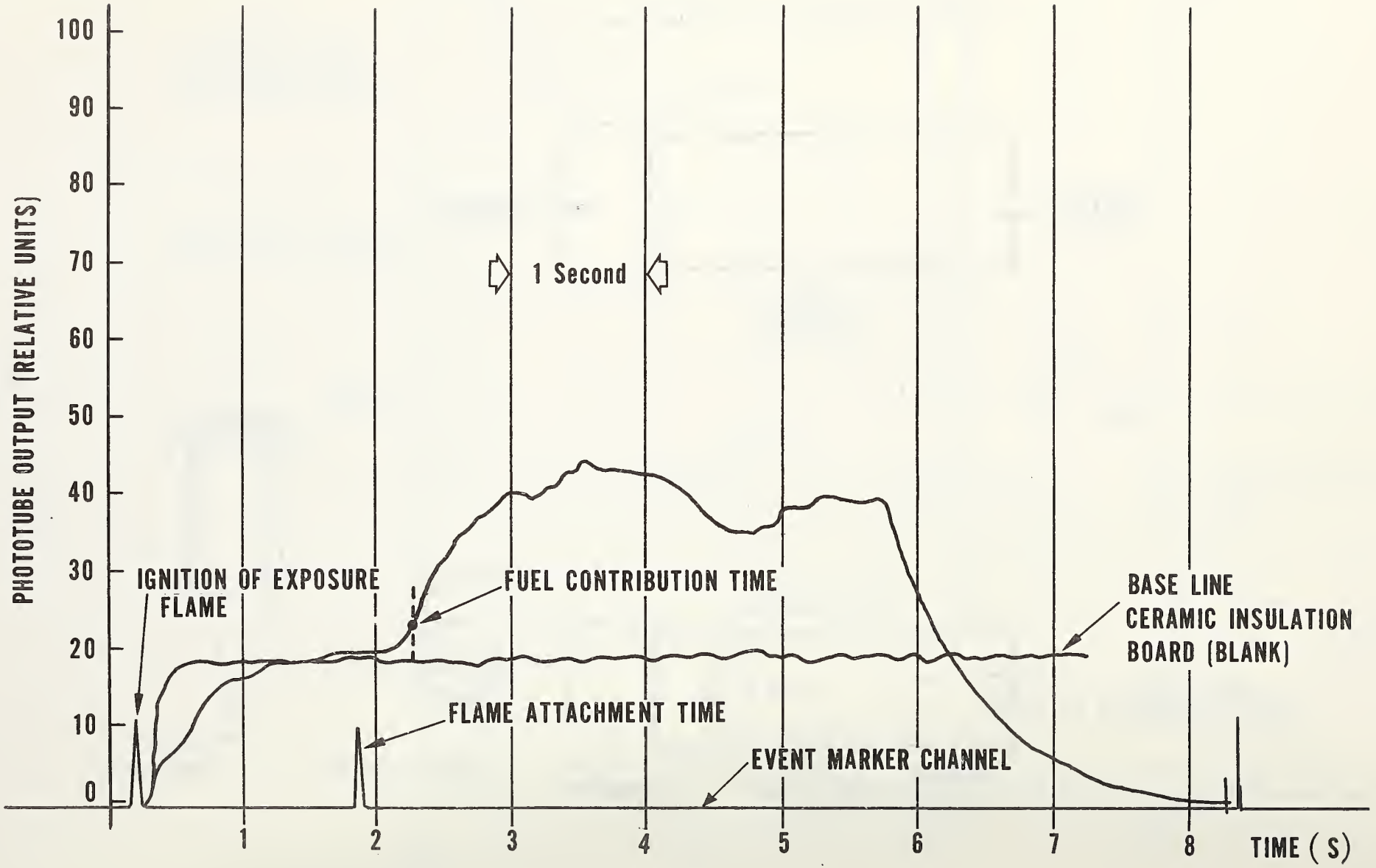


Figure 11. Phototube Record for 32 Kg/m^3 (2 PCF) Polyisocyanurate Foam

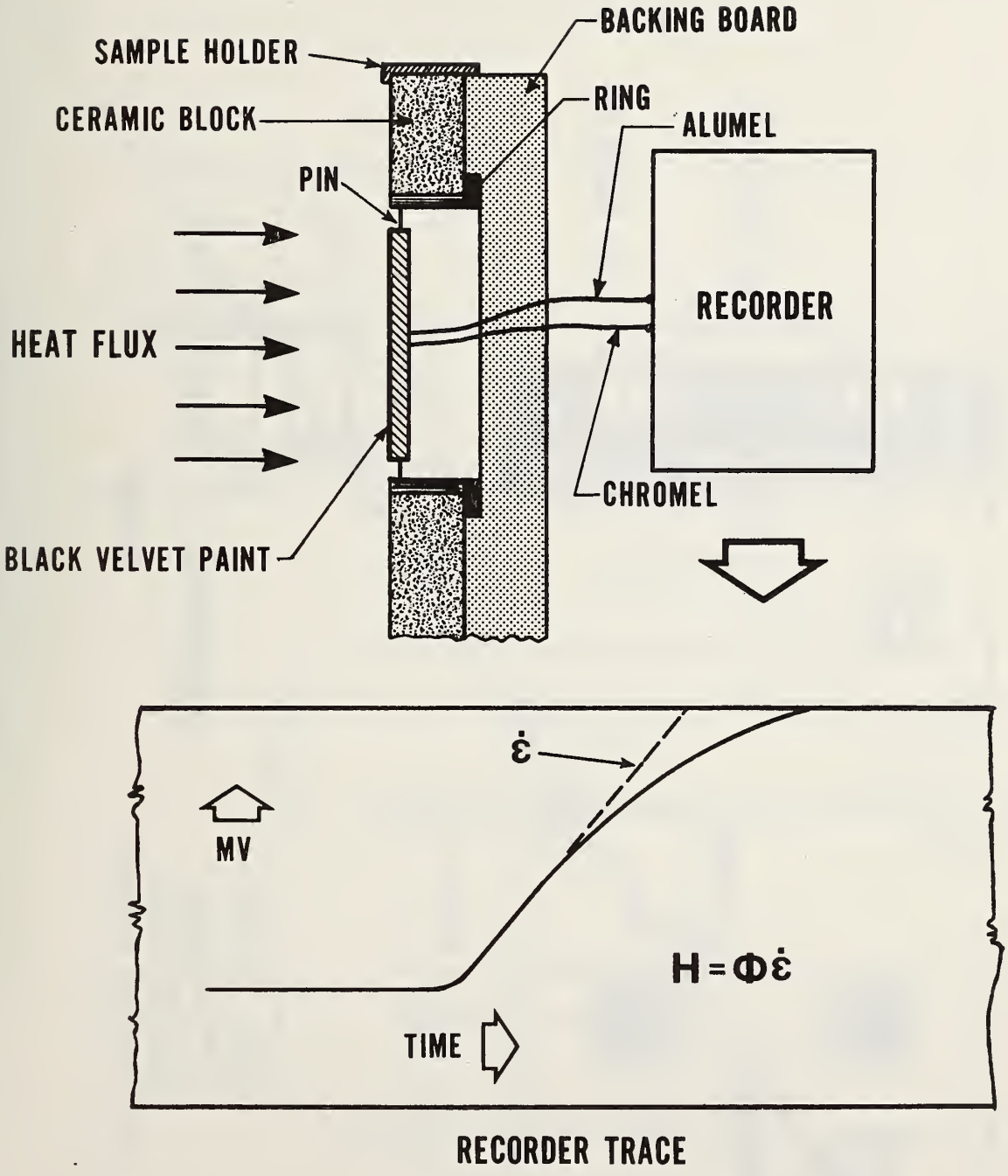


Figure 12.

Schematic Diagram of the Operation of the Copper Disk Calorimeter.

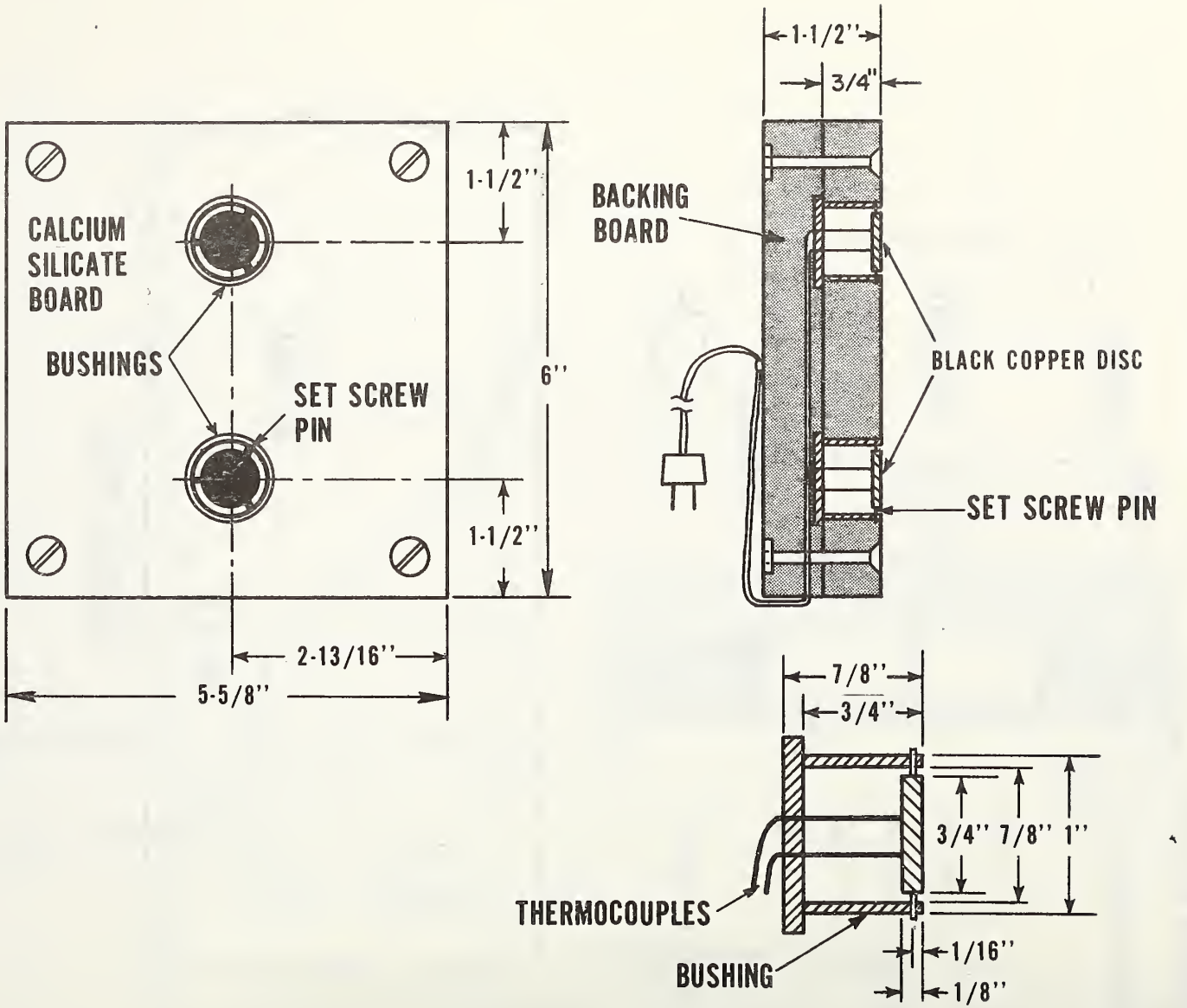


Figure 13. Drawing of the Copper Disk Calorimeter

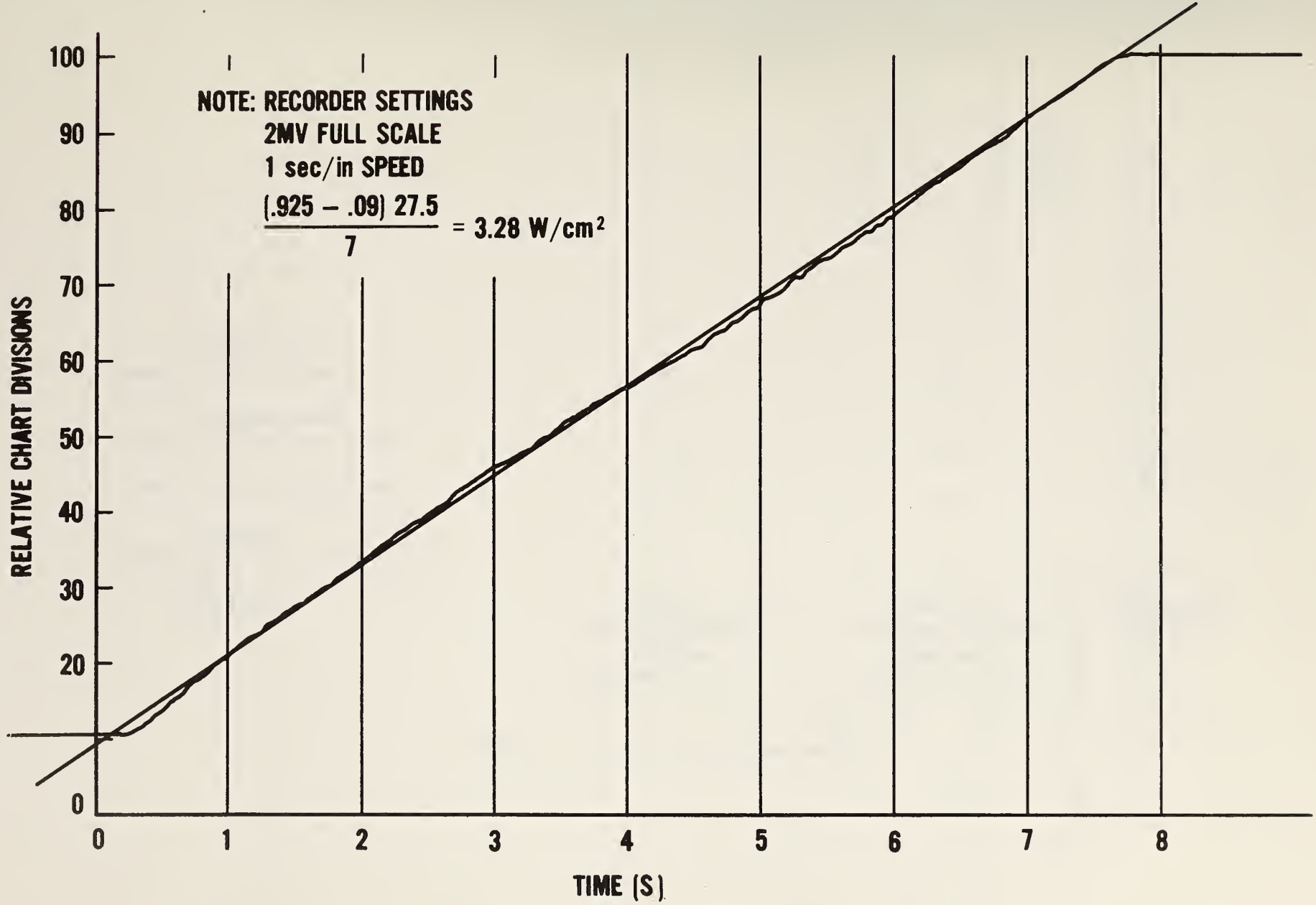


Figure 14. Chart Record of the Incident Flux Measurement

TABLE 1. EFFECT OF SPECIMEN HEIGHT

Material	152-mm (6 in) Specimen Flame Attachment Time (s)	300-mm (12 in) Specimen Flame Attachment Time (s)	Percent Difference
4-mm (5/32-in) Prefinished Plywood	52	56	+7.1
6-mm (1/4-in) Hardboard	94	90	-4.3
13-mm (1/2-in) Wood Fiber Ceiling Board	51	53	+3.8
16-mm (5/8-in) Type-X Gypsum Board	65	66	+1.5

TABLE 2. EFFECT OF CONDITIONING ON IGNITION OF RED OAK

Conditioning Method	Fuel Contribution Time (s)
17 days 23°C (73°F) 50% RH	166
1 day in Oven 60°C (140°F)	131
6 days in Oven 60°C (140°F)	106

TABLE 3. COMPARISON OF TEMPERATURES PRODUCED BY CITY GAS AND METHANE IN THE CENTRAL VERTICAL PLANE OF THE EXPOSURE FLAME

Thermocouple Height in Relation to the Specimen	City Gas (°C)	CP Methane (°C)
Top	638	621
Mid-Height	693	716
Bottom	682	660
Average	671	666

TABLE 4. COMPARISON OF INCIDENT HEAT FLUXES FOR CITY GAS AND METHANE

	CITY GAS INCIDENT HEAT FLUX (kW/m^2)		CP METHANE INCIDENT HEAT FLUX (kW/m^2)
	34		32
	30		31
	32		32
	33		32
	33		30
	30		35
AVERAGE	32	AVERAGE	32

TABLE 5. TIMES TO FLAME ATTACHMENT AND FUEL CONTRIBUTION

Material	Density kg/m^3	Density lb/ft^3	Number of Specimens Tested	Average Time to Flame Attachment (s)	Standard Deviation Time to Flame Attachment (s)	Average Time to Fuel Contribution (s)	Standard Deviation Time to Fuel Contribution (s)	Comments
50 mm (2 in) Fire Retardant Polyurethane Cellular Plastic Insulation UL - "D"	29	1.8	4	2.7	0.59	0.5	0	
50 mm (2 in) Fire Retardant Polyisocyanurate Cellular Plastic Insulation UL - "A"	30	1.9	4	2.9	0.25	1.6	0.75	
50 mm (2 in) Fire Retardant Polyurethane Cellular Plastic Insulation UL - "B"	30	1.9	4	2.6	0.48	1.1	0.25	
25 mm (1 in) Aluminum Foil Faced Polyisocyanurate Cellular Plastic Insulation UL - "AB"	40	2.5	3	45.0	14.73	54.0	0	* Foil burned through rapidly on one test. Specimen showed minor damage with no fuel contribution.
25 mm (1 in) PVC Nitrile Rubber Foam	115	7.2	5	9.0	1.14	12.0	2.07	
25 mm (1 in) PVC Nitrile	120	7.2	6	16.0	1.52	19.0	7.15	

*Only three tests conducted because supply of materials was limited.

TABLE 5 (cont.)

Material	Density kg/m^3	Density lb/ft^3	Number of Specimens Tested	Average Time to Flame Attachment (s)	Standard Deviation Time to Flame Attachment (s)	Average Time to Fuel Contribution (s)	Standard Deviation Time to Fuel Contribution (s)	Comments
13 mm (1/2 in) Redwood, Unfinished	433	27	4	31	2.45	35	2.38	
4 mm (5/32 in) Prefinished Lauan Plywood	593	37	4	47	3.77	52	4.20	
5 mm (3/16 in) Lauan Plywood	465	29	4	48	4.55	60	5.44	
6 mm (1/4 in) Untreated Prefinished Lauan Plywood UL - "H"	545	34	4	51	3.59	56	4.03	
4 mm (5/32 in) Lauan Plywood 0.51 mm (0.020 in) Fire Retardant Vinyl Laminated to Surface	656	41	4	82	10.15	97	8.33	One test stopped before fuel contribution occurred.
4 mm (5/32 in) Lauan Plywood 2 Coats Brand-Y Intumescent Paint	721	45	3	234	22.50	283	46.88	*
4 mm (5/32 in) Lauan Plywood 2 Coats Brand-Z Intumescent Paint	721	45	3	243	8.02	NFC†	-	*
13 mm (1/2 in) Wood Fiber Ceiling Board, Painted	288	18	4	53	3.37	NFC	-	
13 mm (1/2 in) Wood Fiber Ceiling Tile, Fire Retardant Treated	336	21	4	NFA†	-	NFC	-	Glowing ignition noted on all tests.

*Only three tests conducted because supply of materials was limited.
†NFA = No Flame Attachment; NFC = No Fuel Contribution.

TABLE 5 (cont.)

Material	Density kg/m^3	Density lb/ft^3	Number of Specimens Tested	Average Time to Flame Attachment (s)	Standard Deviation Time to Flame Attachment (s)	Average Time to Fuel Contribution (s)	Standard Deviation Time to Fuel Contribution (s)	Comments
6 mm (1/4 in) Hard Board Smooth One Side	913	57	4	78	3.30	96	4.79	
13 mm (3/4 in) Red Oak Unfinished, Sanded	929	58	3	58	0.58	72	5.86	*
13 mm (3/4 in) Red Oak Unfinished, Sanded	1137	71	3	100	19.40	125	16.26	* No fuel contribution on one test.
13 mm (1/2 in) Fire Retardant Treated, Exterior Douglas Fir Plywood UL - "C"	577	36	3	126	20.30	NFC†	-	*
13 mm (1/2 in) Regular Gypsum Board with Factory Applied 0.2 mm (0.008 in) Vinyl Surface Decoration	737	46	6	27	3.71	NFC	-	
13 mm (1/2 in) Regular Gypsum Board, Unfinished	673	42	6	50	4.03	NFC	-	
16 mm (5/8 in) Type-X Gypsum Board, Unfinished	737	46	6	60	4.69	NFC	-	
13 mm (1/2 in) Type-X Gypsum Board, Unfinished	737	46	6	61	2.79	NFC	-	

*Only three tests conducted because supply of materials was limited.
†NFA = No Flame Attachment; NFC = No Fuel Contribution.

TABLE 5 (cont.)

Material	Density kg/m^3	Density lb/ft^3	Number of Specimens Tested	Average Time to Flame Attachment (s)	Standard Deviation Time to Flame Attachment (s)	Average Time to Fuel Contribution (s)	Standard Deviation Time to Fuel Contribution (s)	Comments
25 mm (1 in) Gypsum Core Board, Unfinished	800	50	6	71	4.20	NFC†	-	
8 mm (5/16 in) MH Gypsum Board, Unfinished	737	46	6	74	3.93	NFC	-	
13 mm (1/2 in) Water Resistant Gypsum Backer Board	737	46	6	78	7.39	NFC	-	
13 mm (1/2 in) Gypsum Sheathing	769	48	6	82	5.98	NFC	-	
13 mm (1/2 in) Gypsum Formboard	769	48	6	83	4.69	NFC	-	
8 mm (5/16 in) MG Gypsum Board Printed Face Paper	865	54	4	91	30.52	NFC	-	
8 mm (5/16 in) MH Gypsum Board Sand Paint Textured Finish	657	41	4	NFA†	-	NFC	-	Specimen showed only slight damage from the exposure flame.

†NFA = No Flame Attachment; NFC = No Fuel Contribution.

TABLE 6. FLAME ATTACHMENT TIMES IN THE EASE OF IGNITION TEST AND FULL-SCALE ROOM FIRE TESTS

		Flame Attachment Time (s) Ease of Ignition Test	Flame Attachment Time (s) Full-Scale Fire Test	Reference Identification*
1	8-mm (5/16-in) Gypsum Board Printed Surface	101	76 90 100	[10,11]
2	4-mm (5/32-in) Prefinished Lauan Plywood with Two Coats Intumescent Paint	234	190 200	[10,11]
3	4-mm (5/32-in) Prefinished Lauan Plywood	52	60 95	[10,11]
4	4-mm (5/32-in) Prefinished Lauan Plywood	62	69 75	[10,11]
5	6-mm (1/4-in) Prefinished Lauan Plywood Factory Intumescent Treated Surface	124	125	[10,11]
6	4-mm (5/32-in) Prefinished Lauan Plywood with Two Coats Intumescent Paint	244	170 290	[10,11]
7	4-mm (5/32-in) Lauan Plywood with 0.51-mm (0.020-in) Fire Retardant Vinyl Surface	82	154	[10,11]
8	4-mm (5/32-in) Lauan Plywood with 0.51-mm (0.020-in) Fire Retardant Vinyl Surface	87	145	[10,11]
9	8-mm (5/16-in) Gypsum Board Painted Surface	101	60	[10,11]
10	6-mm (1/4-in) Prefinished Lauan Plywood	59	60	[10,11]

*Test program reference numbers found in section 9.

TABLE 6 (cont.)

		Flame Attachment Time (s) Ease of Ignition Test	Flame Attachment Time (s) Full-Scale Fire Test	Reference Identification
11	16-mm (5/8-in) Particle Board Unfinished	153	192 156 186	[9]
12	6-mm (1/4-in) Prefinished Douglas Fir Plywood	105	132 168	[9]
13	4-mm (11/64-in) Lauan Plywood Sanded Finish	95	150 198	[9]
14	3-mm (1/8-in) Melamine Finished Hardboard	151	192 210 192	[9]
15	13-mm (1/2-in) Fiberboard Acoustic Tile Painted Surface	74	126 138	[9]
16	50-mm (2-in) Flame Retardant Polyurethane Cellular Plastic 1.9 PCF Density	2.6	30	[2]
17	13-mm (1/2-in) Exterior Douglas Fir Plywood (Flame Retardant)	126	132 105	[2]
18	6-mm (1/4-in) Prefinished Plywood	51	105 65	[2]
19	50-mm (2-in) Flame Retardant Polyurethane Cellular Plastic 2.5 PCF Density	1.0	14	[2]
20	50-mm (2-in) Flame Retardant Polyurethane Cellular Plastic 2.0 PCF Density	1.0	40	[2]
21	50-mm (2-in) Flame Retardant Polyisocyanurate Cellular Plastic 2.3 PCF Density	1.0	20	[2]
22	13-mm (1/2-in) Flame Retardant Wood Particle Board	225	265	[2]

NOTE: The ignition delay times for the full-scale fire tests are typically longer than that experienced with the ease of ignition test as a result of the inherent delay time required for the fire to build up in the wood cribs.

TABLE 7. COMPARISON OF EASE OF IGNITION RESULTS WITH FULL-SCALE ROOM FIRE TESTS AT UL [2]

Designation	Material	Thermal Inertia ($K\rho C$) $kW/m^2 \cdot K$	Fuel Contribution Time (s)	Peak Heat Release Rate kW/m^2	Flame Spread Classification	Time of First Reported Flame Spread Tunnel (s)	UL Full-Scale Fire Tests	
							Wall Ignition Time (s)	Flames Out of Doorway (s)*
S	Polyisocyanurate	10^{-5}	1	21	22	4	20	80
A	Polyisocyanurate	10^{-5}	1	8	23	4	14	100
R	Polyisocyanurate Foil-faced	10^{-5}	∞	< 3	27	20	135	∞
G	1/2-in Treated Douglas Fir Plywood	$3 \cdot 10^{-3}$	70	< 3	23	36	119	∞**
H	1/4-in Untreated Plywood	$3 \cdot 10^{-3}$	72	120	178	39	85	280

*These times include the fire buildup time in the wood crib.
**90 percent of room area affected by fire.

TABLE 8. PRECISION TESTS WITH STANDARD HARDBOARD SPECIMENS

Test No.	Density kg/m^3	Density lb/ft^3	Time to Flame Attachment (s)	Time to Fuel Contribution (s)
1	1009	63	112	136
2	993	62	106	134
3	1009	63	105	132
4	1041	65	111	141
5	1041	65	102	131
6	1041	65	116	145
7	1025	64	114	140
8	1041	65	112	140
9	1025	64	105	135
10	1041	65	111	144
11	1041	65	111	143
12	1009	63	105	131
		Average	109	138
		Standard Deviation	4.4	5.1
		Coefficient of Variation	4.0	3.7

APPENDIX A
IGNITION TEST APPARATUS

A.1 Burner and Specimen Holder

A sketch of the test apparatus appears in figure 1 and detailed drawings in figures 8 and 9. Two specimens 140 mm (5.5 in) wide and 152 mm (6 in) high face each other 53 mm (2.1 in) apart. The burner consists of two water-cooled brass blocks 114 mm (4.5 in) high, 152 mm (6 in) wide, and 25.4 mm (1 in) thick, facing each other with a gap of 50 mm (2 in) between them. Methane gas passes into the gap through a horizontal row of 1.9-mm (1/16-in) diameter holes, 12.7 mm (0.5 in) apart, located 9.5 mm (0.38 in) up from the bottom of each block and extending across its width. The holes are drilled into a cylindrical plenum, 9.5 mm (3/8 in) in diameter, running along the width of the block.

The gas enters the burner plenum through the back of the brass block with the connection centered on the plenum. One end of 3.2-mm (1/8-in) i.d. soft copper tubing is fitted to the block, and the other end is connected to a solenoid valve with a 7.1-mm (9/32-in) orifice. The brass blocks also contain a network of intersecting 9.5-mm (3/8-in) diameter holes which provide a path for cooling water. The water leaving the first block passes through the second one before being discharged into the drain. A chromel-alumel thermocouple is formed at top of the rear surface of the second water-cooled block in order to monitor its temperature. The 10 mil wires are peened into the block at a distance of 6.4 mm (1/4 in) apart in order to insure that the thermocouple junction is in the block itself.

The specimen test frames extending above the two water-cooled blocks hold the specimens 53 ± 1 mm (2.1 ± 0.04 in) apart and shield their edges from the exposure flame. Each specimen is held against the frame by two 9.5-mm (0.38-in) wide clamps which contact its back surface adjacent to the vertical edges. The back surfaces of the specimen are open to the atmosphere except where they are contacted by the clamps. This assembly is attached to a bottom plate which is mounted on a 406-mm (16-in) long and 254-mm (10-in) wide table. The area of the table between the two blocks is cut away so that the air for combustion can be drawn in from below by free convection.

A.2 Cabinet

The table is located in an aluminum cabinet 610 mm (24 in) long, 762 mm (30 in) high, and 305 mm (12 in) deep with a pyrex viewing window in the door. Openings 230 mm (9 in) wide and 76 mm (3 in) high, 76 mm (3 in) from the bottom of each end of the cabinet admit fresh air. There is also an opening 108 mm (4.25 in) wide and 140 mm (5.5 in) deep at the top of the cabinet to permit the escape of combustion products. The cabinet must be located under an exhaust hood.

A.3 Spark Igniter

Electrical spark igniter electrodes are mounted to the table bottom, and they extend horizontally to the center of the apparatus and then are bent vertically upward through the opening between the burners. Screw

clamps are attached to the top of the electrodes where steel tips are secured. The electrodes are positioned horizontally and on the same plane as the gas burner holes. The spark gap is set at 3 mm (0.125 in). The electric current for the spark igniter system is supplied by a solid state high voltage induction coil with a built-in DC power supply, catalog number 79803, which is sold by Central Scientific Company.[1]

A.4 Phototube and Marker Circuits

An RCA type 922 vacuum phototube[1] which is used for determining the time of fuel contribution by the specimen is mounted on the front access door of the test chamber. The phototube is mounted horizontally in a 41 x 76 x 98-mm (1.6 x 3.0 x 3.9-in) aluminum container which is open on the top and bottom to allow for air cooling. The side adjacent to the door glass is also open to provide for the collection of light from the chamber. Aluminum foil is wrapped around the phototube with a 3.2-mm (0.125-in) hole to admit the light. The elevation of the hole is 250 $\pm$ 10 mm (9.8 $\pm$ 0.4 in) above the top of the block. This is required to prevent the phototube current from exceeding its operating limit. There is no focusing so the phototube is exposed to a wide field of view as seen in figure 10. A toggle switch is used to turn the phototube circuit on and off. The output of the phototube is connected to one channel of a high input impedence chart recorder. A 0.8 μF capacitance is

[1] Certain commercial equipment, instruments, or materials are identified in this paper in order to adequately specify the experimental procedure. In no case does such identification imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the material or equipment identified is necessarily the best available for the purpose.

placed across the input terminals of the recorder to reduce fluctuations in the phototube output. The second channel is connected to a time marker circuit also shown in figure 10 which consists of a normally open push button switch located on the lower front panel of the test cabinet and wired in series with a 1.5-V battery. Figure 11 shows a phototube and time marker record of time to flame attachment and time to fuel contribution.

A.5 Gas Supply

A toggle switch located on the front panel is used to actuate the normally closed solenoid gas valves. Methane gas which is used for producing the exposure flame is supplied from a gas cylinder to a pair of 0 to 0.2 L/s (0 to 25 SCFH) rotometers with control valves at their inlets where the gas flow rate is monitored and the exposure flame is controlled. Nylon braid reinforced PVC tubing is used to feed the gas from the flowmeter outlets to the solenoid valves. The tubing inside diameter is 6.4 mm (1/4 in).

A.6 Cooling Water

Cooling water is supplied to the test cabinet by 6.4 mm (1/4 in) nylon reinforced PVC or equivalent tubing and it used for connecting the cooling system inside the cabinet. All tubing connections are fitted with hose clamps. The cooling water return line has a flow gauge which indicates the water flow rate.

APPENDIX B
COPPER DISK CALORIMETER

B.1 Description

A copper disk calorimeter shall be used for measuring the total incident heat flux received by the specimen surface in the ease of ignition test apparatus. Basically, the calorimeter consists of two blackened copper disks with thermocouples attached to their backs. One unit is shown schematically at the top of figure 12. Their front surfaces are flush with the surface of a calcium silicate board of the same size as the test specimens as seen in figure 13. The heat flux at the locations of each copper disk is determined from its rate of temperature rise. The thermocouple output voltages are fed to a chart recorder which provides a record of the temperature histories.

The disks made of oxygen-free high purity copper are 3.2 $\pm$ 0.03 mm (0.125 $\pm$ 0.001 in) thick and 19.1 $\pm$ 0.2 mm (0.75 $\pm$ 0.01 in) in diameter. Chromel and alumel wires of 0.30 mm (0.012 in) diameter are attached to the rear of the disk by peening the wires into individual 0.34-mm (0.0135-in) diameter holes drilled 1 mm (0.04 in) deep and 6.4 mm (0.25 in) apart. Each hole is to be 3.2 mm (0.13 in) from the center of the disk. This provides an effective chromel and alumel thermocouple whose junction is located within the disk. A brass bushing is made with an inside diameter of 22.3 mm (7/8 in) and 1.6 mm (1/16 in) walls. It has a 3.2-mm (1/8-in) flange on one end and three 1.2-mm (3/64-in) set screw holes on the other. The holes are located 120° apart around the circumference and

set screws are used to support the disks flush with the end of the bushing. The flange on the opposite end acts as a retainer that holds the assembly in the correct position when it is placed in the calcium silicate insulation board. Two pieces of 19.1-mm (3/4-in) thick board are cut 140 mm (5.5 in) wide and 152 mm (6 in) high. Two 25.4-mm (1-in) diameter holes are drilled through one board along the vertical centerline, centered 41 mm (1.6 in) from the top and bottom edges, respectively. A 6.4-mm (1/4-in) diameter hole is drilled at each corner of both boards. A portion of the second calcium silicate board is milled to provide seating for the bushings and an exit channel for the thermocouple wires. The bushings containing the calorimeter disks are placed into the large holes and the boards are secured together by screws at each corner. The function of the second, or backing, board is to lock the bushings in position and prevent gas leaks around the discs. The thermocouple wires are brought out through the milled channel. Two thin even coats of 3M flat black velvet paint[1] are spray-applied to the front surface of the calorimeter disks.

B.2 Theory of Operation

The total heat flux is determined from the rate of temperature rise of the copper disk using the equation

$$H = \rho z c \dot{T}/\alpha \ , \qquad (1)$$

[1] Certain commercial equipment, instruments, or materials are identified in this paper in order to adequately specify the experimental procedure. In no case does such identification imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the material or equipment identified is necessarily the best available for the purpose.

where α is the absorptivity of the black paint on the exposed surface (0.97) specified by the manufacturer, ρ is the density of copper (8960 kg/m^3), Z is the thickness, c is the specific heat of copper (380 J/kg·K), and $\dot{T}$ is rate of temperature rise (°C/s) of the disk (31.8 mm). It is assumed that the thermal conductivity is high enough that the disk is at a uniform temperature. It is also assumed that there are no heat losses from the specimen. This is approximately true during the early stage of the exposure when the temperature rise is very low. It is also important that the disk is supported in such a way as to minimize the heat conduction through the supports. The operation is shown schematically in figure 12.

The rate of temperature rise is determined from the slope of the recorder trace using the relation

$$\dot{T} = \frac{dT}{d\varepsilon}\,\dot{\varepsilon}\ , \qquad (2)$$

where $\frac{dT}{d\varepsilon}$ is the calibration constant of the thermocouple (24.6 K/mV) and $\dot{\varepsilon}$ is the slope (mV/s) of the linear portion of the recorder trace at the beginning of the exposure.

Combination of (1) and (2) yields

$$H = \rho z c \frac{dT}{d\dot{\varepsilon}}\,\dot{\varepsilon}/\alpha = \Phi\dot{\varepsilon}\ , \qquad (3)$$

where $\Phi = \frac{\rho z c}{\alpha}\frac{dT}{d\varepsilon}$ is the calibration factor which is calculated to be 274 $kW/m^2 \cdot mV$.

In order to ensure that the temperature measured is that of the disk rather than that of a junction just outside, the thermocouple wires are separated so that the junction is made inside the disc. The result is a copper-alumel junction in series with a chromel-copper junction. Since the temperature is the same for both junctions, the total voltage produced is the same as that from a chromel-alumel thermocouple.

B.3 Heat Flux Measurement

In order to determine the total incident heat flux exposure in the ease of ignition apparatus, the following procedure is used:

A. Preheat the apparatus for 3 minutes with the calcium silicate boards in the specimen holders.

B. Replace one board with the copper disk calorimeter.

C. Connect the calorimeter to a strip chart recorder and set the span at 5 mV and the chart speed in the 1 to 5 second per inch range.

D. Start the recorder.

E. Turn on the spark ignitor.

F. Turn on the gas.

G. Allow the exposure flame to burn for 8 to 10 seconds or until the pen goes off scale.

H. Turn the gas off and allow the calorimeter to cool before additional runs are conducted. (Cooling rate may be increased by blowing air over the calorimeter disk.)

I. Measure the slope $\dot{\varepsilon}$ in mV/s of the linear portion at the beginning of the recorder trace. This slope should be constant for several seconds in order to be regarded as a good run. (See figure 14).

J. The total incident heat flux in kw/m^2 is calculated using equation 3 in section B.2.

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☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

A test for the ease of ignition of interior finish materials by flame exposure was developed. Two specimens, 140 mm (5.5 in) wide by 152 mm (6 in) high, face each other at a distance of 53 mm (2.1 in) apart. A methane diffusion flame passes between their surfaces and extends to about 152 mm (6 in) above them. The operator observes the specimen surface and records the time-to-flame attachment. A phototube, which views the exposure flame, shows a marked increase in output when the specimens start contributing fuel. The times-to-flame attachment were compared with the observed times of wall involvement in some full-scale tests. The ignition sensitivity is expressed by the time-to-flame attachment and by the time-to-fuel contribution. The times-to-flame attachment measured in the ignition apparatus generally ranked 22 materials with the observed times of wall involvement in full-scale tests. The results of this test may be useful as one factor in computer models of fire growth in enclosures.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

Building materials; fire tests; flame attachment; heat flux; ignition; room fires; wall coverings

13. AVAILABILITY

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