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BRIEF DESCRIPTIONS OF SOME FIRE-TEST METHODS USED FOR WOOD AND WOOD-BASE MATERIALS[1]

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Introduction

Because wood can be made to burn vigorously under some conditions does not mean that it will behave similarly under all fire exposure. Wide variations in the conditions that govern fires in different types of buildings produce different fire effects.

A person trying to light a wood fire soon recognizes that he can do so only after he has brought together a number of favorable conditions. Important factors are the density of the wood, its moisture content, the thickness of the pieces, their arrangement, amount of draft, and the element of time, all in relation to the amount of heat available for producing ignition.

It is inconceivable that all of the factors affecting fires could be incorporated and controlled in one laboratory test. Accordingly, a number of different test methods are used to get information on specific aspects of fire performance.

Fire tests of wood and wood-base materials may serve any of several purposes. They may be used to classify materials as to (1) ignitability, and (2) tendency to spread flame or to permit flame to penetrate, or (3) to evaluate the resistance to fire of various structural elements or construction systems. Most fire tests used in the laboratory may be classified as tests of: (1) ignitability, (2) flame spread characteristics, or (3) resistance to fire penetration.

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

The purpose of this paper is to describe some of the different types of tests in the classifications mentioned above. While the technical literature describes a great many different types of tests, many of them varying either in detail or basic approach, it was not possible to include a description of all in this paper. A number of common and widely used tests will, however, be discussed. Many of the references quoted in this report contain additional references. In addition, library bibliography No. 2, revised August 1953, published by the Joint Fire Research Organization of the Department of Scientific and Industrial Research and Fire Offices Committee (14)[3] of Great Britain contains an excellent listing of publications dealing with this subject.

In the discussion following, the various test procedures have been grouped in three classifications. Obviously, however, the line of division between these classifications is indistinct, in that a test in one class may also provide information basically derived from another class.

Ignitability

Ignitability is simply the tendency to burn. The less the ignitability, the greater the external heat must be before the material concerned will contribute to the fire. Therefore, the ignition temperature is important in classifying material.

Temperature of ignition has been defined by various authorities in different ways. One that seems suitable takes the ignition temperature as that temperature at which the rate of heating in the substance being tested exceeds the rate of heating induced by the external source of heat; the specimen must have visible combustion in the form of a glow or flame (16).

The ignition temperature for a material is not a single value. McNaughton (19) points out that the "ignition temperature" is greatly influenced by the duration of exposure. That is, a piece of wood can be caused to ignite over a range of temperatures. The time required for ignition to occur will be greater at the lower end of the range. Thus, ignitability data are intimately related to the details of the test procedure.

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[3] Underlined numbers in parentheses refer to references at the end of this report.

Ignition in a Muffle Furnace at 750° C. with Pilot Light (British Standard)

The British Standards Institution includes an ignitability test in Standard BS-476, Fire Tests on Building Materials and Structures (7). The specimens are each 2 by 1-1/2 by 1-1/2 inches. Specimens made of materials that are normally less than 1-1/2 inches thick are made of sufficient layers to achieve a final thickness as near as possible to but not exceeding 1-1/2 inches. Six specimens are required. Three of these are dried by heating to a temperature of 100° C. for 6 hours, then allowed to cool to room temperature in a dry atmosphere. If not tested immediately, they are stored in a hermetically sealed dry container until test. The remaining three specimens are kept for a period of 1 week before testing in a desiccator containing solid calcium chloride.

The test is carried out in an electrically heated furnace with a central cylindrical opening 3 inches in diameter and vented at the bottom (fig. 1). In test, the furnace temperature is raised to and stabilized at 750° C. before the specimen is inserted. Furnace temperature is measured by a thermocouple placed at the level of the center of the furnace and 3/8 inch from the internal wall of the heating tube. The specimen is then inserted centrally in the tube with its long axis vertical, a period no longer than 30 seconds being allowed for this operation. The specimen is heated for 15 minutes. A two-piece adjustable asbestos-wood cover is used to close off the furnace opening but is so arranged that there is an aperture 1 square inch in area with its center coinciding with the axis of the furnace heating tube. A pilot gas flame of specified size is located immediately above this opening on the axis of the heating tube. A material is considered combustible if, during the test period, any one of the six specimens flames, produces vapors that are ignited by the pilot flame, or causes the temperature of the furnace to be raised 50 Centigrade degrees or more above 750° C.

Ignition by Radiation in a Quartz Cylinder (Prince at F. P. L.)

Some of the early work on ignitability was done by Prince (20). In one of his tests a wood specimen 1-1/4 by 1-1/4 by 4 inches was suspended in a quartz cylinder heated by electrical resistance elements (fig. 2). The test specimen was lowered into the hot cylinder and allowed to remain there until it ignited, or for 40 minutes if ignition did not occur. Exposure was at various temperatures from 150° C. to 450° C. If the piece ignited, the length of time before ignition was recorded by means of a stopwatch. The piece was then lowered into a cooler chamber and allowed to burn not longer than 3 minutes. The specimen was then weighed and the weight loss determined.

Ignition by Radiation with Pilot Light (Prince at F. P. L.)

A second type of test used by Prince utilized a chamber made of 1/4-inch asbestos board 22 inches long, 10 inches wide, and 7 inches deep (fig. 3). The upper 10 inches were used as a heating chamber. Heat was obtained from an electric heating coil made by winding flat nichrome ribbon on a silica plate 4 inches square. This coil was protected by another silica plate of the same size. The two plates were fastened together and placed in the apparatus so that the heat was radiated to the lower part of the test specimen, which was placed 3/4 of an inch away. A small gas pilot light was allowed to burn just below the center of the heating plate. The pilot light was made so that it could be flashed up in front of the heated specimens. During test, the silica plate was heated to approximately 325° C. When the plate temperature was constant, the test specimen was put in place. The radiated heat caused the wood to give off volatile, flammable gases. The pilot light was flashed up past the face of the specimen at 5-second intervals until these gases ignited. The length of time necessary to ignite the specimen was recorded by means of a stopwatch. After ignition, the specimen was allowed to burn for a predetermined period, the length of the period depending upon the thickness and treatment.

Ignition in a Glass Jar with Hot Air (Brown)

A test developed by Brown (8) made use of controlled air flow as opposed to the natural draft utilized by Prince. In Brown's tests, the specimen was suspended inside a pyrex jar which, in turn, was supported in an electric furnace (fig. 4). Perforated copper coils inside the jar furnished preheated air. A thermocouple was placed inside the specimen and a second thermocouple placed between the pyrex jar and the wall of the furnace. The difference in temperature between the two thermocouple readings was obtained by a galvanometer. Ignition in this case was taken to be the point at which the difference in readings between two thermocouples no longer varies regularly. The temperature of the specimen at the time at which this break occurred was taken as the ignition temperature. Flaming of the specimen in place was not the criterion of ignition. However, in many cases, the specimen was actually glowing or flaming when removed from the furnace; if not, in practically all cases it could be readily blown into glow and flame as soon as removed.

Ignition by Contact with Electrically Heated Wire (Landt and Hausmann)

Landt and Hausmann (18) described a somewhat similar test, except that the electrical resistance heating elements were wrapped directly about the wood. In their tests, a 7-foot length of No. 30 B&S gage nichrome wire (6.5 ohms per foot) was wrapped about the sample. The test piece was 1/8 by 1 by 10 inches. Grooves were milled into the edges of a 4-inch center portion. The grooves were 1/32-inch deep and 15/1000-inch wide, and so spaced as to permit 10 turns of wire to the inch. The sample was supported at both ends and placed in a protecting container to shield it from air currents. The container was a box 12 by 24 by 16 inches high with the front and top removed. The container may not be completely closed, as the gas produced during the test may prevent access of air to the sample. To permit a gentle stream of air to pass over the sample, yet to guard against disturbing air currents, the box with the sample mounted in it was placed in a hood with the open side of the box toward the front. The front sash of the hood was then drawn down until a 2-inch opening remained at the bottom. The air passing over the sample supplied it with the necessary oxygen and enabled the products of decomposition and combustion to escape from the surface of the sample itself. A forced draft on the hood was not necessary. Samples were conditioned for 24 hours at 105° C. in a suitable oven before test. The test was started by turning on the current (110 volts). The time from the snapping of the starting switch to the moment the sample burst into flame was noted. The authors report that this point was very definite.

Ignition in a Glass Tube with Hot Air Increasing in Temperature (Graf)

Professor S. H. Graf (16) has reported tests using still a different type of equipment. In his tests, the specimen was inserted near one end of a pyrex tube extending through an oven (fig. 5). Air or other atmosphere could be measured and blown through the tube from the other end. Automatic equipment was used to raise the temperature of the oven at any desired rate. During the test, temperatures were measured in the oven at a point just ahead of the specimen and at a point just behind the specimen. The first noticeable change in the differential temperature or in the slope of the temperature-time curves was taken as an indication of ignition temperature, providing the specimen developed a glow or burst into flames within a reasonable time thereafter. A reasonable time was established as being that time during which there was evidence of an exothermic reaction as shown on the recorder as a displacement of the time-temperature curves from their normal positions relative to another one. The wood specimens were prepared by cutting pieces 2-1/4 inches long and slightly larger in diameter than matches and stacking them into wire racks. These racks were of 2 sizes; approximately 5/8 inch and 1 inch inside diameter and about 2 inches long. They were constructed of loosely coiled chromel wire and served not only to center the specimen, but also as a check on the sample size and as a sort of grate allowing free circulation of the air around the specimen. In tests of paper, it was found that constant results could be obtained when the paper was rolled tightly and inserted in the fire racks.

Ignition by Constant Strong Radiation (British Fire Research Board)

The British Fire Research Board has experimented with the ignition of materials by radiation (13). Radiation from a tungsten lamp was concentrated on an area 2 centimeters square by means of an ellipsoidal mirror (fig. 6). The time to ignite was recorded.

Flame Spread

The tendency for flame to spread on a material is important in determining the passage of fire from one part of a structure to another and thus in exposing fresh fuel to add to the fire. Perhaps more important is the fact that the time for personnel to extinguish a fire or to evacuate a building is dependent on flame spread. Many of the test methods proposed or standardized, particularly for materials which may be used as wall or ceiling surfaces, measure this characteristic.

Fire-Tube Test for Combustibility (ASTM Standard)

A fire-tube test developed at the Forest Products Laboratory about 1928 has been described by Truax and Harrison (23). It has been adopted as a standard by the American Society for Testing Materials(1). Much of the published information concerning the efficacy of various fire-retardant materials in pressure impregnated lumber is based upon this test. The test is suitable also for evaluating or comparing fire-retardant coatings.

The apparatus (fig. 7) consists of a specially constructed beam balance with a sheet metal tube suspended from one arm (1, 26). A Bunsen burner flame can be introduced at the bottom of the tube to envelop the lower end of a specimen suspended within the tube. A thermocouple may be permanently attached to the balance arm for calibrating the flame. The flame is standardized as that from a low-form Bunsen burner with a height of 11 inches ± 1/2 inch with a tall, indistinct inner cone. Such a flame produces a temperature of 180° C. ± 5° C. at the top of the empty fire tube. The standard specimen is 3/8 by 3/4 inch in cross section by 40 inches long, with a tolerance of 1/32-inch in any dimension.

An indicating arm is attached to the balance and moves past a scale in such a way that the percentage loss in weight can be determined at any stage in the test. At the start of the test, the balance is so adjusted that the pointer reads 100 percent when there is no specimen in the tube and 0 percent when the specimen is in place. After the standard flame is applied, readings of percentage weight loss are taken at half-minute intervals from the start of the test until no further loss in weight is indicated. The gas flame is removed after 4 minutes. Usually, the test takes no longer than 10 minutes. Other data, such as duration of flaming, duration of glowing, and the like, are recorded.

Suggitt (22) has described a so-called fire-tube test for evaluating fire-retardant paints. A wood or fiberboard panel 10 by 2-3/4 by 1/4 inch was suspended in a Transite tube. The flame, however, was generated by the use of C. P. acetone. In his test, he used 13 milliliters of this fuel to give a total energy and rate of energy release comparable to that used in the fire-tube test described above. By Suggitt's method, however, weight loss can be determined after completion of the test.

Crib Test for Combustibility (ASTM Standard)

The crib test, which has been standardized by the American Society for Testing Materials (Standard E160-50) (5), is used to measure the combustible properties of wood. It consists essentially of applying a standard flame to a test sample arranged in the form of a crib (fig. 8). The crib is made up of 24 pieces of material sawed to 1/2 by 1/2 by 3 inches ± 1/32-inch and conditioned to equilibrium in an atmosphere maintained at 80° F. and 30 percent relative humidity. The igniting flame is centered below the crib for 3 minutes, after which it is removed. After all flaming and glowing have ceased, the specimen, including any fallen pieces, is weighed and the weight loss determined. Duration of flaming and glowing after removal of the igniting flame is recorded.

Modified Schlyter Test for Flame Spread

The modified Schlyter test used at the U. S. Forest Products Laboratory is an adaptation of a method described by Ragnar Schlyter (26) and is used to measure the tendency of a surface to propagate the vertical spread of fire. This method has proved particularly useful in evaluating fire-retardant coatings. The distinctive feature of the test is a flue between parallel vertical panels for promoting the spreading of flames (fig. 9).

The equipment consists of a frame for holding the panels vertical and parallel, a suitable gas burner, facilities for calibrating the intensity of the igniting flame, and a scale for measuring flame height. The panels used in test measure 11-7/8 inches in width by 31 inches in length. They are conditioned to a moisture content of 7 percent ± 1 percent at the time of test. When oil paint films are to be tested, the painted panels are allowed to season 30 days before testing. The two panels are arranged so that the surfaces to be tested are parallel and facing each other 2 inches apart with the bottom of one 4 inches above the bottom of the other. A scale for measuring the height of flame during the test is mounted behind the test assembly so that the graduations are visible when looking between the two panels. The type of burner to be used depends upon the severity of the test desired. The height of flame on the panel is recorded immediately at the start of the test and at 15-second intervals. The burner is usually removed after 3 minutes of exposure. A record is made of the time flaming and glowing cease and photographs may be taken for a permanent record of the form and area of the burned surface. This test permits a determination not only of distance which the flame spreads but also of the rate of the spread.

A somewhat similar test was used by Suggitt (22) in his evaluation of fire-retardant paints. The panels were 24 by 12 by 3/4 inch and were exposed at a spacing of 1 inch with the bottom of one 2 inches above that of the other. The flame was produced by the burning of 26 milliliters of C. P. acetone. The criterion of good fire-retardant characteristics was based chiefly on the percentage of area which was charred.

Inclined Panel Test for Flame Spread

The inclined panel test used at the U. S. Forest Products Laboratory (26) for measuring the flame spread characteristics of fiber insulation board (24), was adapted from a British Standard (6). The test is one of a number of tests included in a United States commercial standard for fiber insulation board (24). The specimen, a flat 12 by 12-inch panel conditioned to equilibrium at 80° F. and 50 percent relative humidity, is supported on four vertical pointed steel rods at an angle of 45° with the horizontal (figs. 10 and 11). A small cup, placed near the bottom edge of the specimen, contains one cubic centimeter of absolute ethyl alcohol for ignition. The time for flame to reach the upper horizontal edge is noted. One minute after the fuel has been exhausted, any flame or glow in the specimen is noted and extinguished. Time for flame to reach the upper edge, duration of flaming, and area of char are reported.

This test has since been replaced in the British Standard by a radiation test which will be described later.

Horizontal Panel Test for Flame Spread and Combustibility (SS-A-118a)

The horizontal panel test developed by the U. S. National Bureau of Standards is now a part of the Federal Specification for prefabricated acoustical units (25). It is used to classify materials as noncombustible, fire retardant, slow burning, or combustible. The test specimen is in the form of a flat panel 36 by 36 inches, conditioned to equilibrium at 80° F. and 30 percent relative humidity. The test specimen is laid horizontally on the frame and covered with a sheet of 1/2-inch asbestos millboard held down by heavy weights (fig. 12). A standard flame from a gas-air pressure burner is directed against the center of the lower surface of the specimen. The temperature 1 inch below the center of the specimen is measured by a thermocouple and the gas-air mixture regulated according to 1 of 2 standard time-temperature curves. The test duration and the time-temperature curve used depend upon the classification anticipated. For slow burning and combustible materials, the duration is 20 minutes, and for noncombustible and fire-retardant materials, the duration is 40 minutes. The classification is based upon the flaming characteristics of the material, the progress of glowing combustion beyond the area exposed to the flame, and upon the integrity of the specimen.

British Standard Flame Spread Test with Radiation of Varying Intensity (BS 476:1953)

The test sample for the British Standard surface spread of flame test is 9 by 36 inches (7). It is fixed with its long axis horizontal and at right angles to the face of a radiating unit (fig. 13). The radiating unit is required to produce temperatures varying from 500° C. at the near end of the test sample to 130° C. at the far end. Immediately after the sample is exposed to the radiated heat a standard vertical luminous gas flame is applied to the hotter end for 1 minute. As soon as the igniting flame is in contact with the specimen, observations are made of the time of spread of the flame front for measured distances along a line drawn parallel to the long axis and 3 inches from the bottom edge of the specimen. Measurements are continued until the flames have died out or for 10 minutes, whichever is the longer. Material is classified according to the total spread of flame and to the flame-spread rate.

As an appendix to the Standard, there is described a smaller version of a similar test. It is described as not replacing the equipment shown in the body of the Standard, but as having been developed for use by manufacturers and others for preliminary evaluation during the development of materials. The samples in this case are 3-3/4 by 12 inches, and the radiating equipment is 1/3 the size of the standard test equipment.

The same test has been standardized in Australia as Australian Standard Specification No. A30-1935, Amendment No. 2, July 1945. Tests by this method of a variety of materials, including fiberboard, plaster board, plywood, and building papers, have been described (11).

A modification of this test method now under study at the U. S. National Bureau of Standards involves placing the specimen with its face, rather than an edge, toward the face of the radiant panel (figs. 14 and 15).

Horizontal Furnace for Flame Spread (ASTM Standard method)

The American Society for Testing Materials describes in its Standard E84-50T (2) a horizontal tunnel for a fire hazard classification of building material that is used by the Underwriters' Laboratories, Inc. (21). The test tunnel is essentially a duct having an inside width of 17 inches and a length of 25 feet (figs. 16 and 17). The sides and base of the duct are insulated and of noncombustible material, one side being provided with numerous observation ports. The removable top or roof of the duct consists of an insulated structural framework 25 feet long and 20 inches wide formed into a flat, noncombustible surface that is fitted to the top of the duct so as to preclude air leakage. The test material is applied to the lower face of this framework in the same manner as it will be applied in actual use. Gas burners and air inlets are provided at one end of the chamber. The other end is vented and fitted with a damper for regulating air velocity. A light source and photoelectric cell are located in the vent to provide a measure of smoke intensity. A thermocouple is inserted near the vent end of the sample 1 inch from the exposed surface and 24 feet from the fire end. The rate of air movement and the air conditions are controlled. The flame is adjusted so that a test sample of select Grade A red oak will become enveloped in flame throughout its entire length in 6 minutes.

The test is continued for 10 minutes, unless the sample is completely consumed in the fire area before that time. Fire spread, as determined on the red oak samples mentioned above, represents a classification of 100. Flame spread with an asbestos-cement board in the sample location is tested by the standard procedure and the flame spread and other characteristics are considered to represent a classification of 0. Other materials are classified in this scale.

Forest Products Laboratory Horizontal Furnace

Now under development at the Forest Products Laboratory, Madison, is a medium-size horizontal furnace (fig. 18). The purpose is to develop a smaller and less expensive tunnel that will provide data similar to those obtained by the large horizontal furnace test method of ASTM Standard E 84-59T (2), and that will also be simpler and cheaper to operate. In its present form, it consists of an insulated square metal tunnel 12 by 12 inches in inside cross section by 8 feet long, with a gas burner at one end, a vent at the other, and a removable top on which the specimen may be mounted. The specimen is 15 inches wide and 8 feet long. The specimen is mounted so that 12 inches of the width is exposed to fire in the test.

The test procedure has not yet been standardized, since the furnace is still in the developmental stage and progressive modifications in both construction and method of operation are being made.

Roof-Corner Flame Spread Test

The roof-corner test is one of a number of tests designed by the Forest Products Laboratory to introduce into the test specimen characteristics similar to those encountered in structures. It permits the correlation of flame-spread tendency based on the smaller scale tests already mentioned with the flame-spread characteristics that might be experienced in a structure.

The specimen (26) consists of a section built to represent the corner of a framed attic with a shingle roof (fig. 19). The floor is 4 feet square and rests upon 2- by 8-inch joists that have plasterboard attached to the lower side. One end wall between the floor and roof is closed. The other end and the front are open. Details of floor and end wall construction and fire-retardant treatment of the lumber forming the inside surfaces are varied to meet the performance desired. The assembly is supported from the floors of an enclosed building. The joist covering and the method of support are intended to simulate the ceiling and room space of a room below. The igniting flame may be generated by any of a number of sources such as kerosene, magnesium incendiary bombs, and thermit incendiary bombs. Temperatures are measured at various points on the specimen and records at about 1/4-minute intervals are made of flame spread on the interior of the roof, the floor, and the end wall.

Side Wall Flame Spread Test

In the side wall flame spread test, two 4 by 8 foot wall panels are used (26). One is attached to a side wall and one to the ceiling of a cinder block fire test room, leaving an air space of about 1 inch between the panels and the wall (fig. 20). Thermocouples are fixed on the face and back of the panels and about the room for measuring the temperature. A crib weighing 2,245 grams ± 2 grams built of 20 hard maple sticks 7/8 by 7/8 by 12 inches in size and conditioned to 7 ± 1 percent moisture content is built at the base of the side wall. A pan containing 50 cubic centimeters of 95 percent ethyl alcohol is ignited beneath the crib to start the igniting flame. Progress in the fire up the wall and onto the ceiling is followed by observing both flame height and temperatures each minute. Experience has shown that one thermocouple location is superior for indicating fire behavior. This location is on the ceiling above the crib fire and 6 inches from the top and center of the wall panel. The crib is permitted to burn completely, and the wall fire is allowed to burn freely for at least 13 minutes before it is extinguished.

Corner Wall Flame Spread Test

The corner wall flame spread test is carried out as described for the side wall test, except that the wall panel is split lengthwise into two 2 by 8 foot panels that are fastened to the two walls and a corner (26). Two panels, one 4 by 4 feet and the other 4 by 8 feet, are fastened to the ceiling to form an "L" along the wall (fig. 21).

Fire Penetration Tests

In addition to combustibility and tendency to spread flame, the resistance of a material or structural assembly to the penetration of flame is important in determining whether the material or assembly will perform satisfactorily in resisting fire. Tests in this category are usually made with one side exposed to a heat source controlled to a standard time-temperature curve.

Small (20- by 20-inch) Vertical Furnace for Fire Penetration Tests

A small (20- by 20-inch) vertical furnace is used by the U. S. Forest Products Laboratory (26) to obtain preliminary fire penetration data on material before conducting tests on a larger scale (fig. 22). The furnace is equipped with pipe outlets for discharging fuel gas to various parts of the interior. It has a 20-inch square opening for receiving the test specimen. The gas supply is delivered through metering devices and is controlled by a mixing valve through which compressed air may be introduced when necessary. Ordinarily, all air for combustion is admitted by natural draft through vents at the bottom of the furnace with baffling to get proper distribution. Thermocouples are provided at various points within the furnace and connected to an indicating potentiometer to get direct readings of furnace temperature. Preferably, a specimen is 19-1/2 inches square and is simply inserted within the furnace opening and loosely packed mineral wool is used to caulk the gap between the specimen and the masonry. Observations of furnace temperature and the temperature of the unexposed side of the test panel are made at frequent intervals (2 to 5 minutes). The end point of the test is reached when the fire has burned through some part of the test specimen or when a thermocouple in contact with the outside surface of the panel indicates a temperature of 250° F. above room temperature. At the end of the test, the panel is removed from the furnace and quenched with water. Charring effects and other features that may have influenced failure are examined. The fire resistance of the specimen is taken as the period of exposure up to the time of failure.

Large (10- by 10-foot) Vertical Furnace for Fire Penetration Tests

A larger vertical furnace permits the use of larger specimens (up to 10 by 10 feet) or assemblies possessing practical construction features (26). The furnace is constructed in two parts, one forming the stationary rear and sides, the other a removable front. The stationary part (fig. 23) is provided with gas piping, aspiration-type burners, air ports, thermocouples for determining furnace temperatures, observation ports, chimney damper, and so on. The movable part, constructed to carry the specimen and the masonry that surrounds it, is suspended from trolleys operating on a track system. During the test, the movable front is held rigidly by means of hand wheels and latches against an asbestos rope gasket interposed between the two parts of the furnace. If desirable, the interior of the furnace can be partitioned to accommodate smaller units such as wall assemblies, bulkheads, and door assemblies. Observations of temperature of the furnace and of the panel exterior are similar to those described above. In addition, however, some tests require the impact erosion and cooling effects of a standard hose stream.

Fire Resistance of Building Constructions

ASTM Standard. --Procedures for fire tests of the various elements involved in building construction are described by the American Society for Testing Materials in its Standard E119 (3). Bearing and nonbearing walls and partitions, columns, floors, roofs, and ceilings are covered.

A standard time-temperature curve is prescribed for use (fig. 24). The large vertical furnace described in the preceding section is suitable for tests of vertical units such as walls. Load-carrying elements, such as walls, floors, roofs, and columns, are required to be loaded during test in such a manner as to produce, in the various structural elements, stresses equal to the working stresses used in design.

In test, the construction is subjected to the standard temperature conditions on one face, except for columns, which are exposed on all faces. In most cases, upon completion of fire exposure, the specimen is subject to exposure to a specified hose stream.

Fire resistance is expressed as the time during which the specimen successfully meets certain conditions. These conditions vary somewhat with the particular construction under test, but in general, include: (1) sustaining of applied load during test, (2) no passage of flame, gases hot enough to ignite cotton waste, or of the hose stream, (3) temperature rise on the unexposed face of not more than 250° F., or temperatures at certain points in the supporting structure to be no higher than certain specified values.

British Standard. --British Standard BS 476:1953 (7) contains a very similar test procedure. The time-temperature curve specified duplicates that in ASTM Standard E-119 for periods up to 2 hours, but specifies somewhat lower temperatures for longer periods. The British Standard differs also in that no fire-hose test is required and that the applied load is reimposed 48 hours after completion of the fire test. Classification as to fire resistance is based on the time during which the structure successfully meets certain conditions; these are essentially the same as are contained in the ASTM Standard.

Fire Resistance of Door Assemblies. --Procedures for fire tests of door assemblies contained in American Society for Testing Materials Standard E152 (4) are essentially the same as those just described for building construction except that they have been particularly adapted to doors. Provisions for mounting, clearances, and fit are specified; furnace temperatures and the fire hose test are essentially the same as for building construction. Classification is by the time the assembly remains in place in the opening and is not penetrated by flame or the hose stream. A maximum temperature of the unexposed face is not specified, although such a provision may be included at the option of the parties concerned.

The British Standard previously mentioned includes tests of doors in its general provisions.

Tests of Full-Sized Structures

Tests of full-scale structures, such as dwellings, are, in general, out of the question because of the considerable expense involved. It is known, however, that in many cases the fire characteristics of the structural materials and wall coverings are of importance only during the early stages of a fire. After the fire has progressed to a certain point, the characteristics of room contents become of more importance in determining the progress of the fire.

To simulate the fire performance of large structures, the British have attempted to work with models ranging from 1/20 to 1/5 of a full scale (12, 13). While this work is still in the exploratory stage, indications are that a correlation between scale model and full-size structures are sufficiently good to justify extension of the work.

The Forest Products Laboratory at Madison has experimented along similar lines with tests of fires in single dwelling rooms (10). The procedure has not been standardized but generally the test room was 8 by 12 feet with an 8-foot ceiling height, with two wood frame windows and one wood door (fig. 25). The roof was of 1/4-inch cement board covering the ceiling joists. The floor was 6-inch softwood flooring laid on a softwood subfloor. Two of the walls were of hollow cement tile with no interior paneling. The other two walls were of conventional wood frame construction, finished on the outside with Portland cement stucco applied to metal lath. The interior surfaces of these two walls, as well as that of the ceiling, were covered with various materials, including fiberboard, plywood, plaster, and gypsum wallboard.

The room was furnished with simulated furniture made of sweetgum lumber to simulate chairs, tables, bookcase, and a hall tree (figs. 26 and 27). The chairs were upholstered with burlap, padded with wood shavings. All the furniture was stained and coated with lacquer. In addition to the furniture, burlap floor coverings were used to simulate rugs, cotton cloth drapes were placed at the windows, a cotton table cloth covered the table, and magazines were placed in the bookcase and on the table tops and table shelves. Pieces of burlap were hung from the hall tree to simulate clothing.

Inlet and outlet draft ports were provided and were so arranged that the supply of oxygen could be regulated. Gases from the combustion were vented through chimneys.

Various means of starting the fire to simulate normal hazards were tried. Finally, however, in order to standardize the initial ignition, a crib was chosen. It consisted of 36 pieces of 1/2- by 1/2- by 12-inch sweetgum of 12 percent moisture content, arranged in 6 tiers above a sand bath (fig. 28). The crib weighed 1,030 grams.

The crib was set next to a chair near the table and a large piece of filter paper wet with 25 cubic centimeters of gasoline was laid on the sand and lighted by match. Ignited in this way, these fires had an accelerated start compared to accidental fires that smolder or burn slowly in the early stages. Samples of the combustion gases were taken at intervals for analysis. Suitable manometers were used to measure the variation in air pressure in the burning room. Temperatures were measured at various locations. Heat transfer were measured by thermocouples on the unexposed sides of the wall panel.

In addition to direct measurement of such factors as temperature, heat transfer, and air pressure, valuable information was obtained on the fire behavior of actual dwelling rooms by periodic observations during the course of the fire and by motion pictures, both colored and black and white. It was thus possible to observe the critical stages of the fire and to determine when the characteristics of the wall covering lose their importance.

Correlation of Results

It is apparent from this brief review that there are many different fire test methods in use by many different agencies, and that they differ both in objectives and procedures. Apparently little research has been carried on to compare and correlate the results by different methods.

One correlation study, however, was that by Van Kleeck and Martin (27), in which the results of tests on fiberboard by three different methods were compared. The test materials included a number of boards usually used for interior surfacing, both as manufactured and coated with paint or fire-retardant coatings. The test methods included the horizontal panel test (SS-A-118a), the "mild" Schlyter test, and the inclined panel test. Overall, some correlation among the three test methods was observed. The data showed, however, that performance in one test could not infallibly predict the results of one of the others.

Summary

The great variety of possible test procedures for any one class of fire tests is indicated by this brief review. Each method has certain advantages and disadvantages, but not enough information is available in most cases to permit an adequate comparison of one method with another. A comprehensive program of comparative tests for this purpose is highly desirable, but until such a program is completed it will not be possible to make definite recommendations regarding many of the test procedures.

A few of the procedures described are current generally accepted standards, and it may be assumed that these could be given preferred consideration. These include the following:

Fire Tube Test for Combustibility (ASTM Std. E-69)

Crib Test for Combustibility (ASTM Std. E-160)

Test for Ignition in a Muffle Furnace with Pilot Light (Sec. 1, Brit. Std., BS 476:1953)

British Standard Surface Spread of Flame Test (Sec. 2, Brit. Std., BS 476:1953)

Horizontal Furnace Test for Flame Spread (ASTM Std. E-84)

Fire Resistance Test for Building Constructions and Materials (ASTM Std. E-119)

Fire Resistance Test for Doors (ASTM Std. E-152)

British Standard Fire Resistance Test (Sec. 3, Brit. Std. BS 476:1953)

British Standard BS 476:1953 (Sec. 3) is similar to the two ASTM Standards (E-119 and E-152) and coordination between them should be relatively easy. Australian Standard Specification A30-1935, Amendment No. 2, endorses the British flame spread method of section 2, British Standard BS 476:1953.

The fire-tube test, adopted as a standard by the American Society for Testing Materials, has been extensively used for about 25 years, and has demonstrated its utility as a method for evaluating the combustibility characteristics of wood and the effectiveness of fire-retardant coatings and impregnants. The equipment is simple and easy to operate. The results are reproducible, easy to interpret, and permit differentiation between materials that differ only slightly in fire-resistivity.

In conclusion, it should be noted again that it was not possible to make a complete survey for this report of all fire test methods that may be in use in all countries. Anyone having experience with other methods that can be recommended is invited to submit the procedure details to the authors.

The authors believe that with a moderate amount of revision and coordination, accepted methods are now available for the several classes of fire tests. It may be well to emphasize, however, that much work lies ahead before a fully coordinated and acceptable set of fire tests can be established. In view of the magnitude of the problem, coordinated research should be carried on by as many organizations as possible interested in the fire problem.

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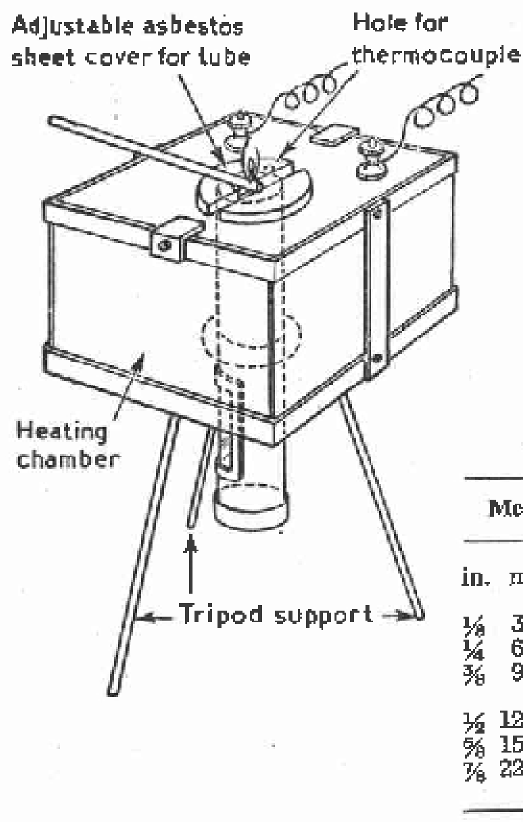
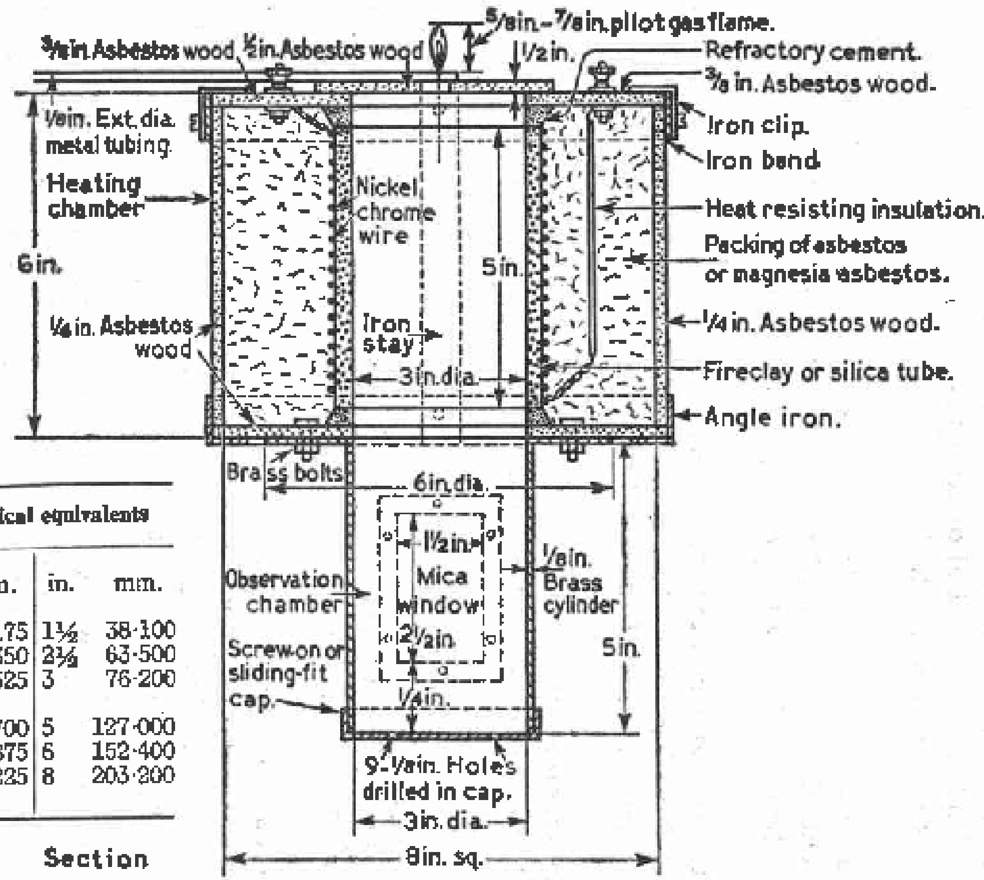


Sketch of apparatus

M 95667 F



Metrical equivalents

in.	mm.	in.	mm.
1/8	3·175	1 1/2	38·100
1/4	6·350	2 1/2	63·500
3/8	9·525	3	76·200
1/2	12·700	5	127·000
5/8	15·875	6	152·400
7/8	22·225	8	203·200

Section

Figure 1. --Apparatus for British Standard combustibility test. Ignition is in muffle furnace at 750° C., with pilot light. (Photograph from British Standard BS 476:1953.)

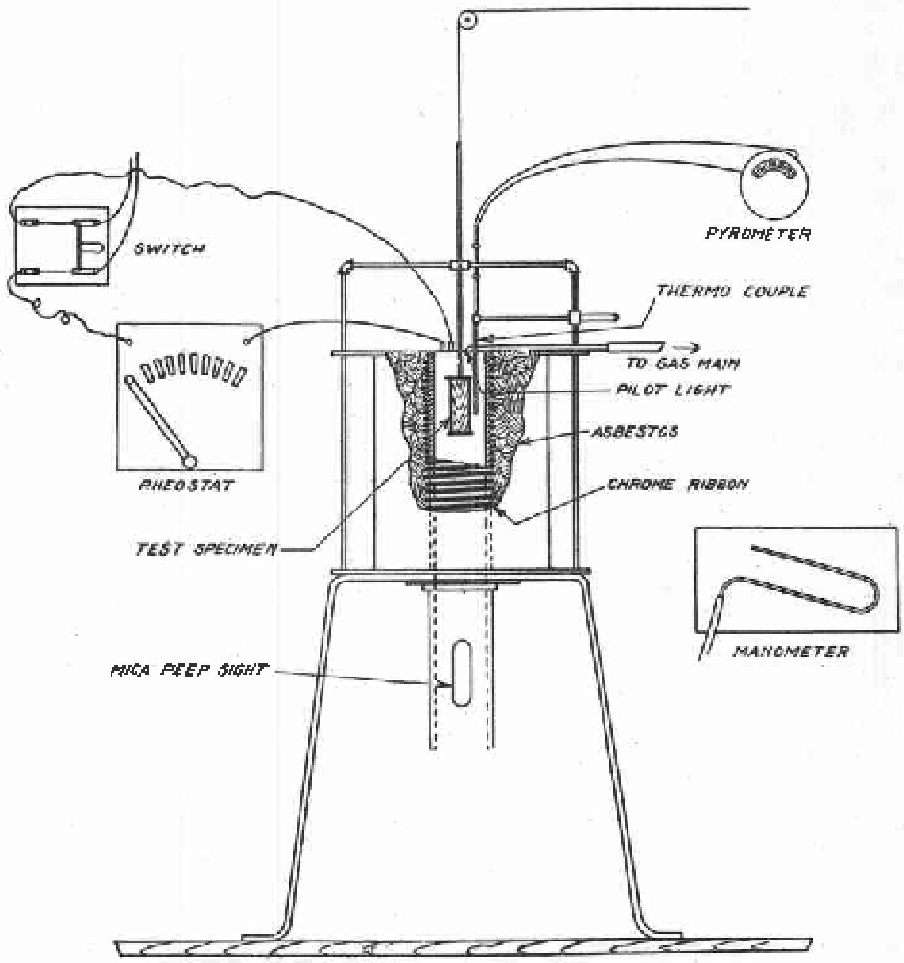


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Figure 2. --Apparatus for ignitability tests used by Prince at Forest Products Laboratory. Ignition is by radiation and pilot light in quartz cylinder. (Photograph from Proceedings of Annual Meeting, National Fire Protection Association, 1915.)

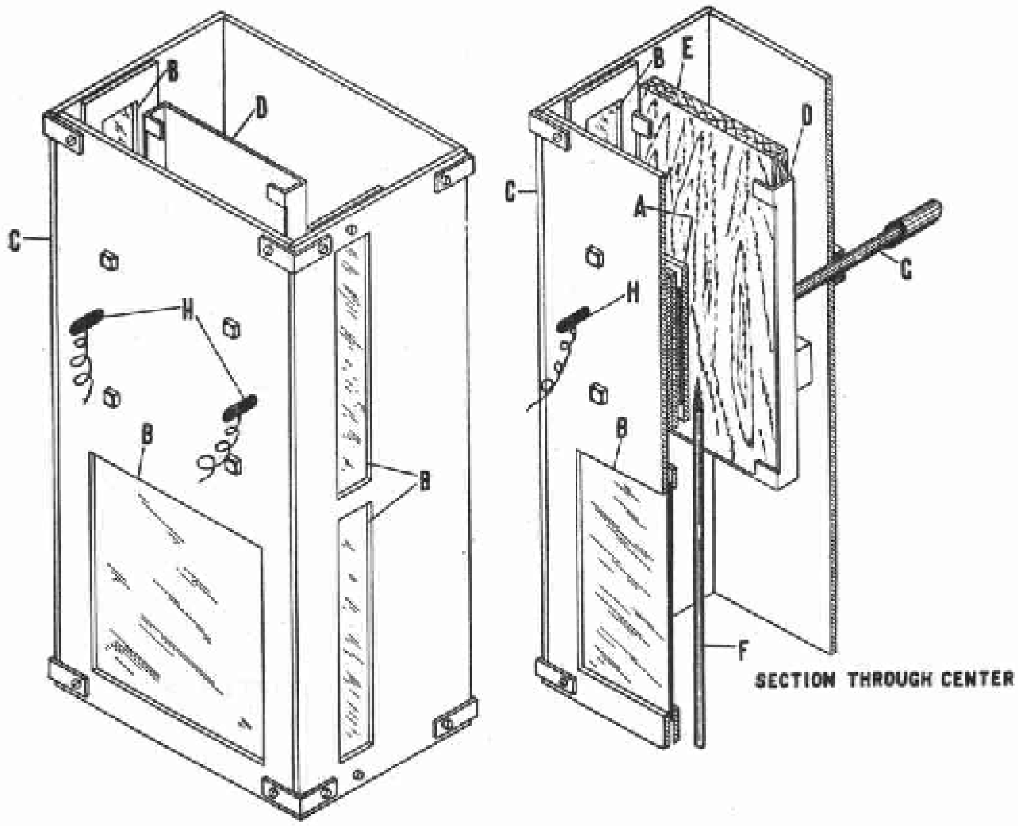

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Figure 3. --Apparatus for ignitability tests used by Prince at Forest Products Laboratory. Ignition is by radiation with pilot light. (Photograph from Proceedings of Annual Meeting, National Fire Protection Association, 1915.)

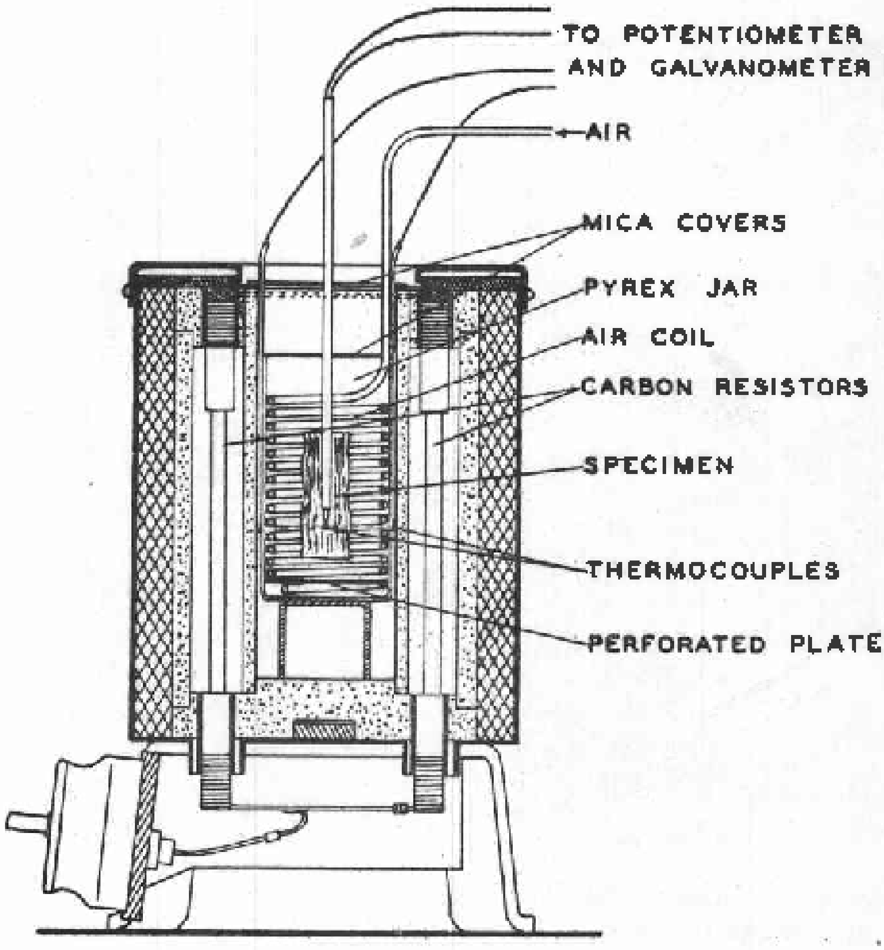

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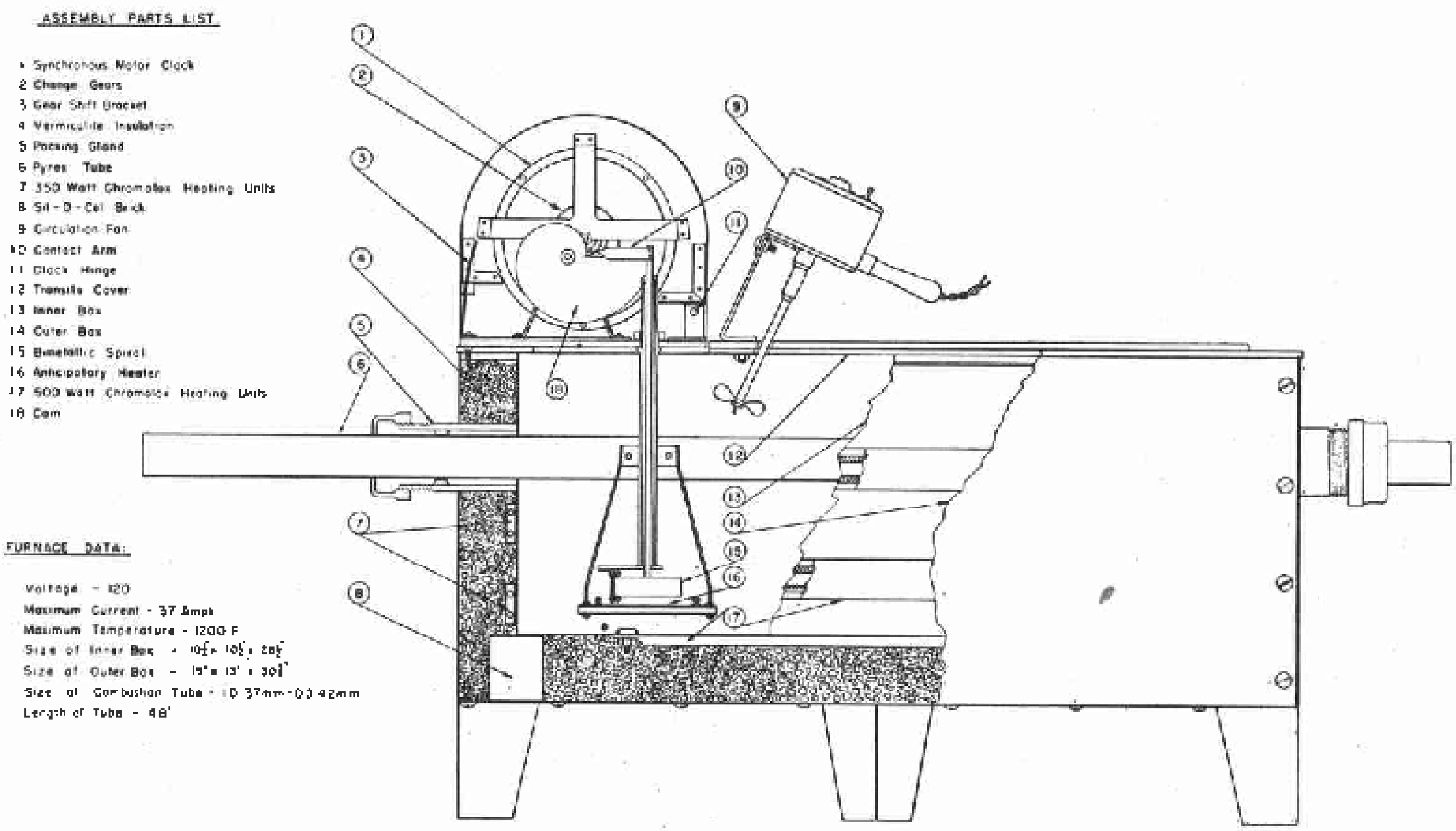
Figure 4. --Apparatus for ignitability tests used by Brown. Ignition is in glass jar and oven with hot air. (Photograph from unnumbered publication, The Catholic University of America.)



M 95666 F

Figure 5. --Apparatus for ignitability tests as used by Graf. Ignition is in glass tube and oven with hot air increasing in temperature. (Photograph from Bulletin No. 26, Engineering Experiment Station, Oregon State College.)

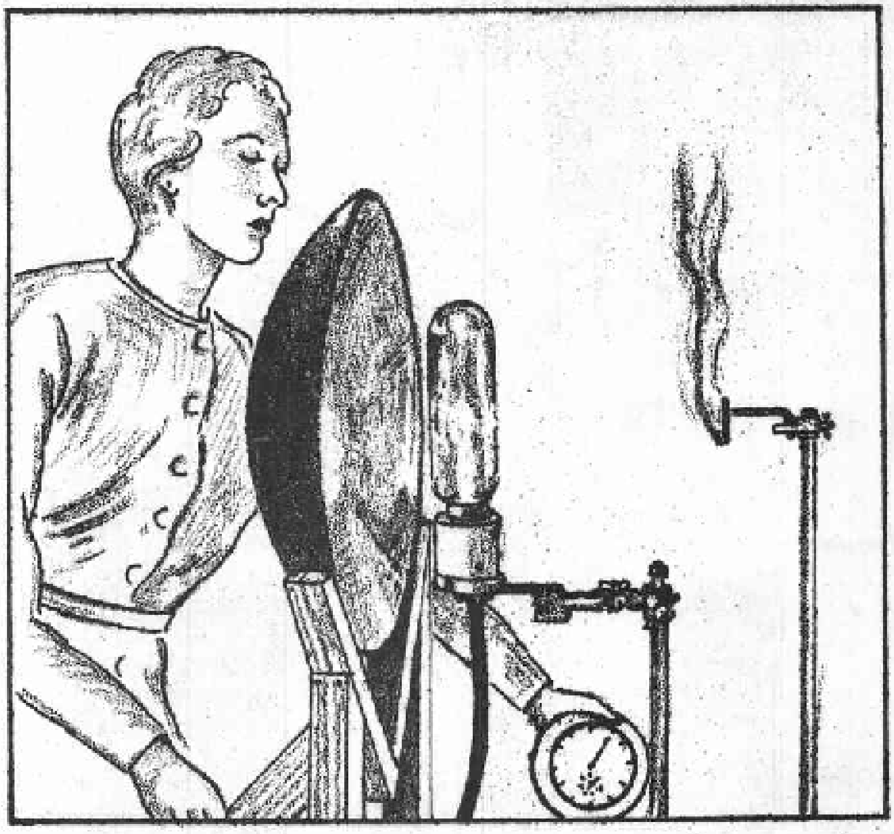


Figure 6. --Apparatus for ignitability tests used by British Fire Research Board. Ignition is by constant strong radiation. (Sketched from photograph in Report of the British Fire Research Board for the Year 1952.)

Z M 95812 F

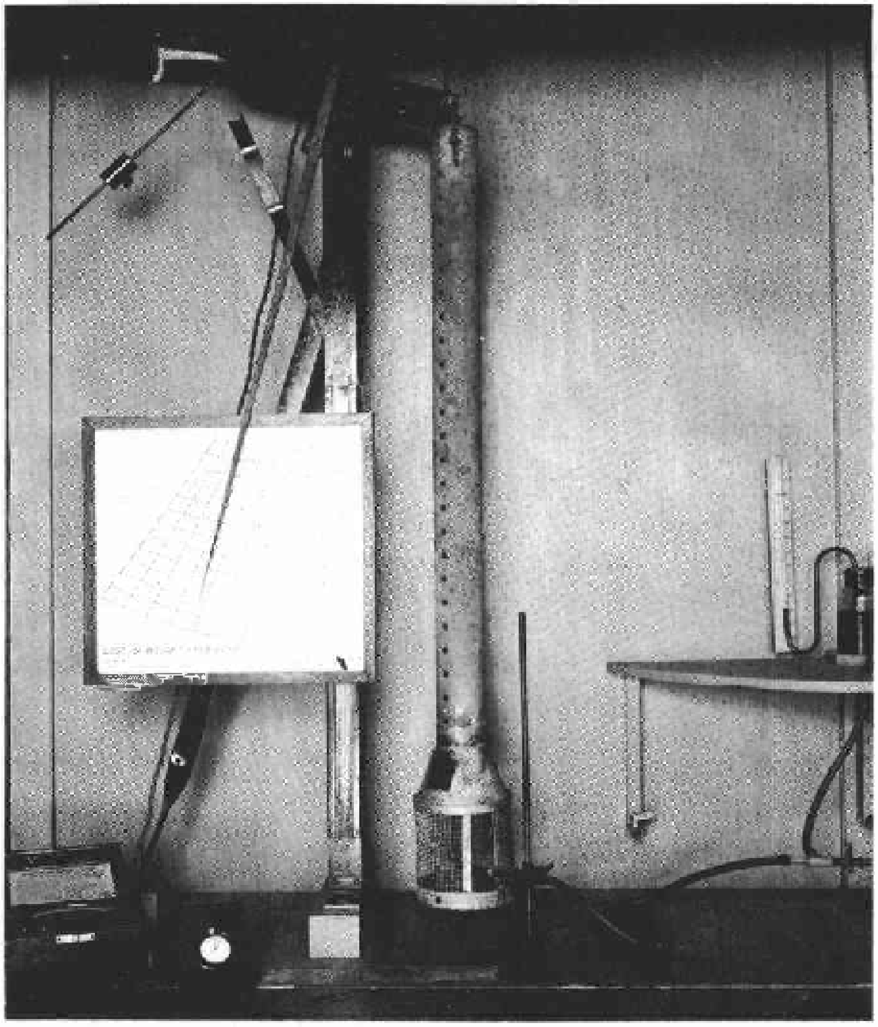


Figure 7. --Apparatus for ASTM Standard fire-tube test for combustibility. (ASTM Standard E 69-50.)

Z M 39179 F

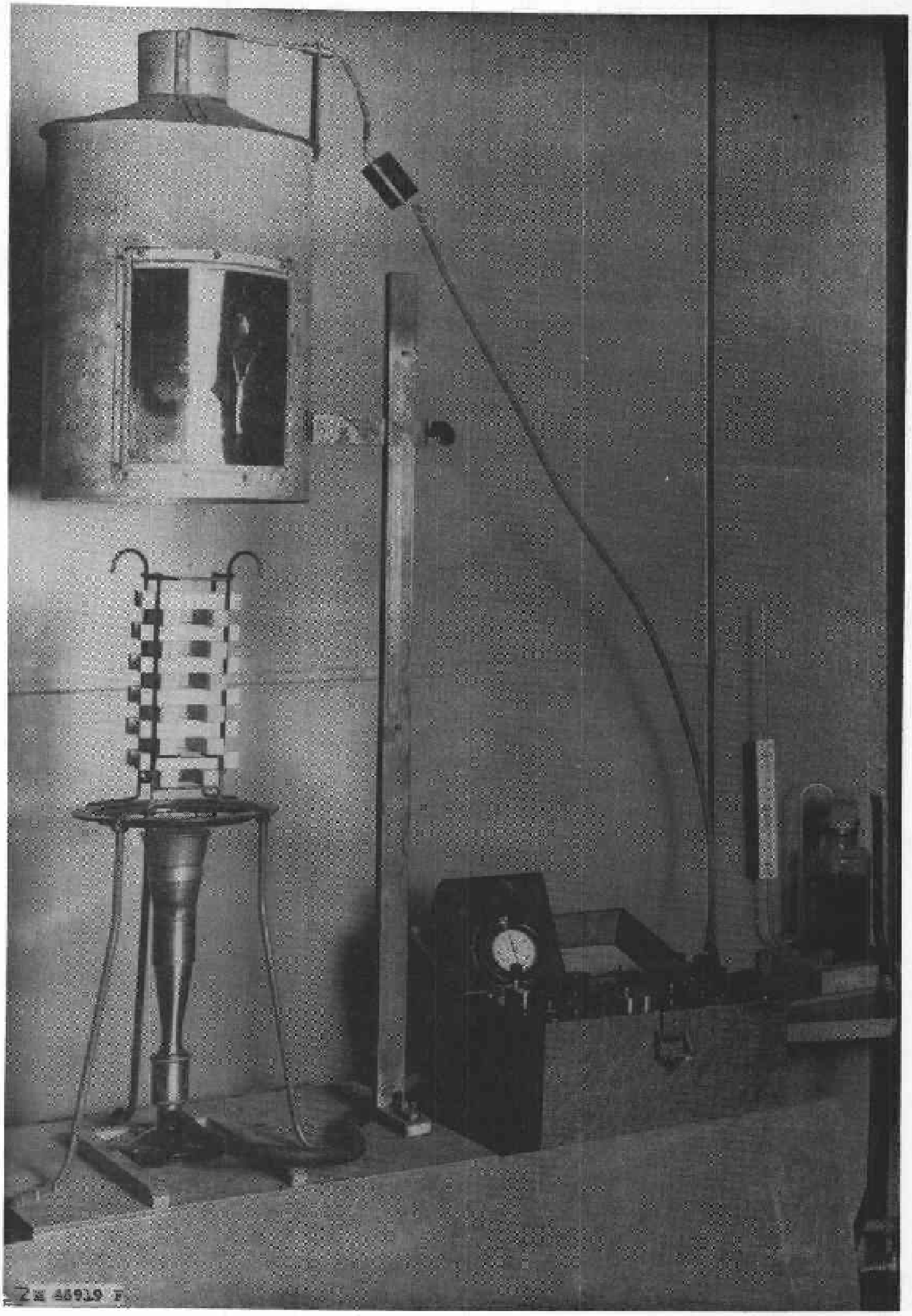


Figure 8. --Apparatus for ASTM Standard crib test for combustibility. (ASTM Standard E 160-50.)

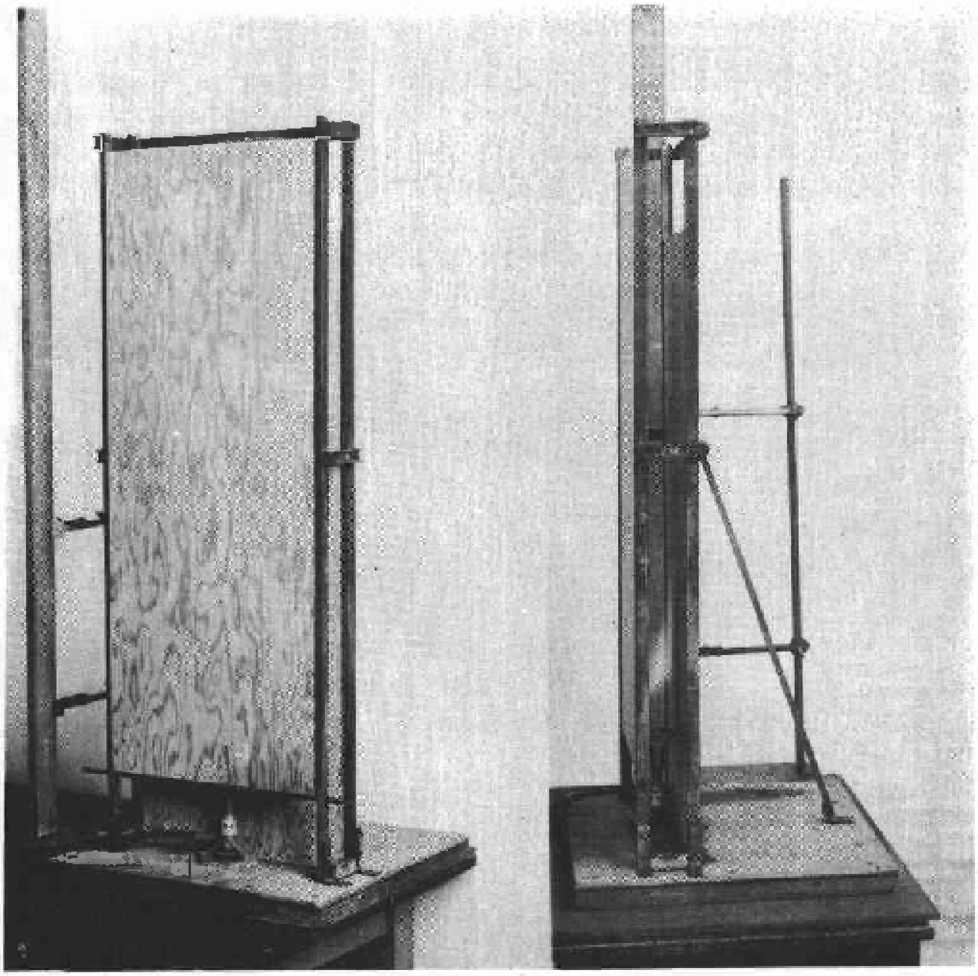


Figure 9. --Apparatus for modified Schlyter test for flame spread.

Z M 90914 F

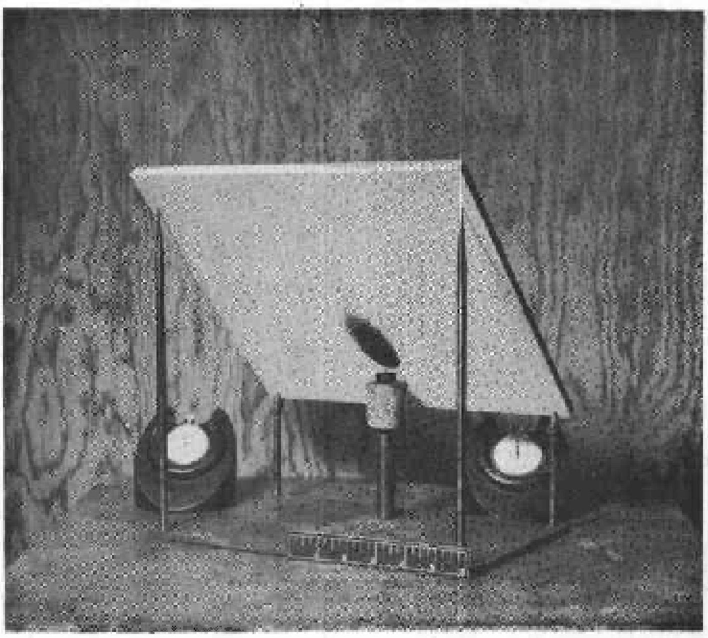


Figure 10.--Inclined panel test for flame spread. Modified by Forest Products Laboratory from former British standard.

Z M 79383 F

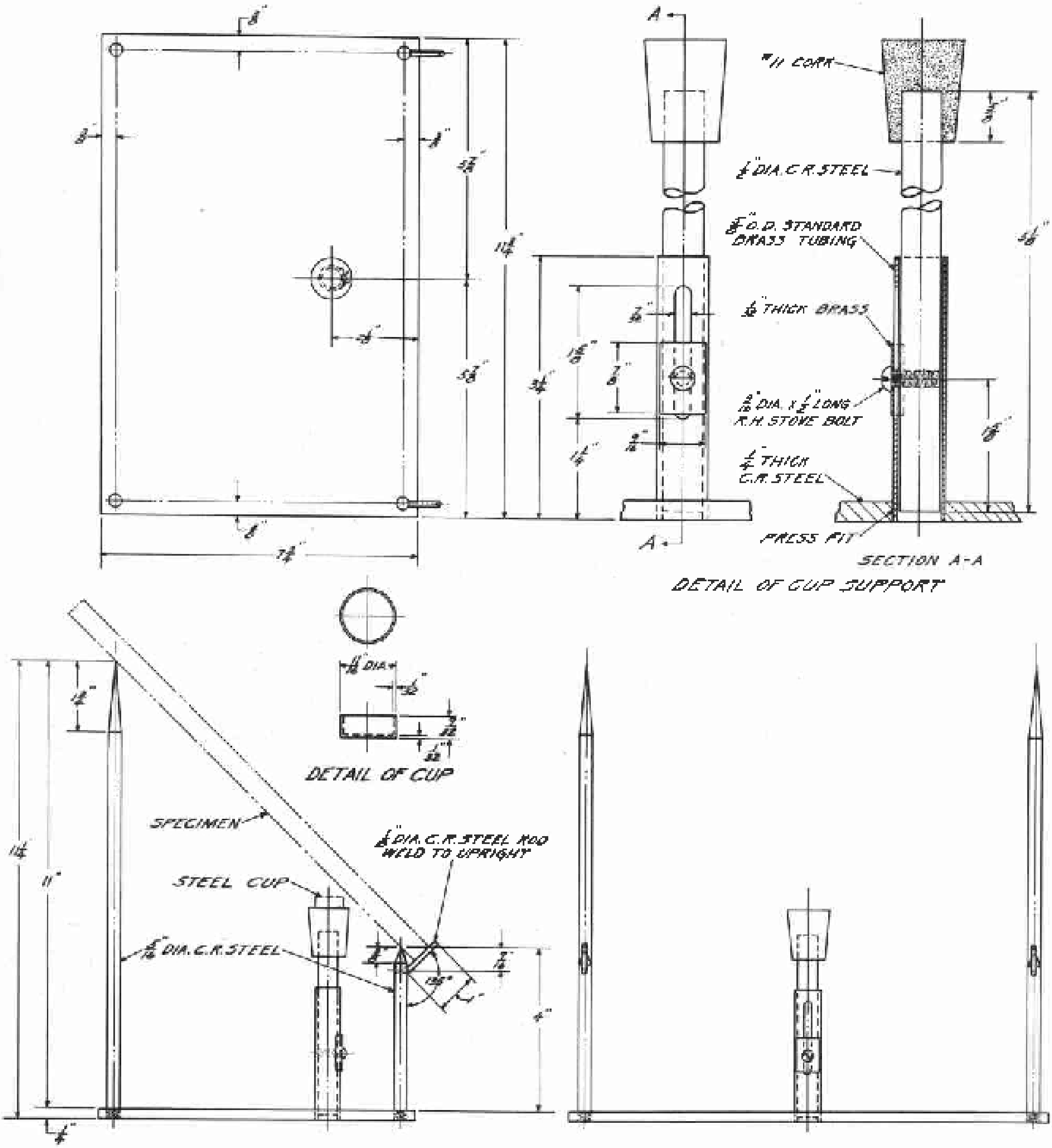


Figure 11. --Details of the equipment used in the Forest Products Laboratory inclined panel test for flame spread.

Z M 87236 F

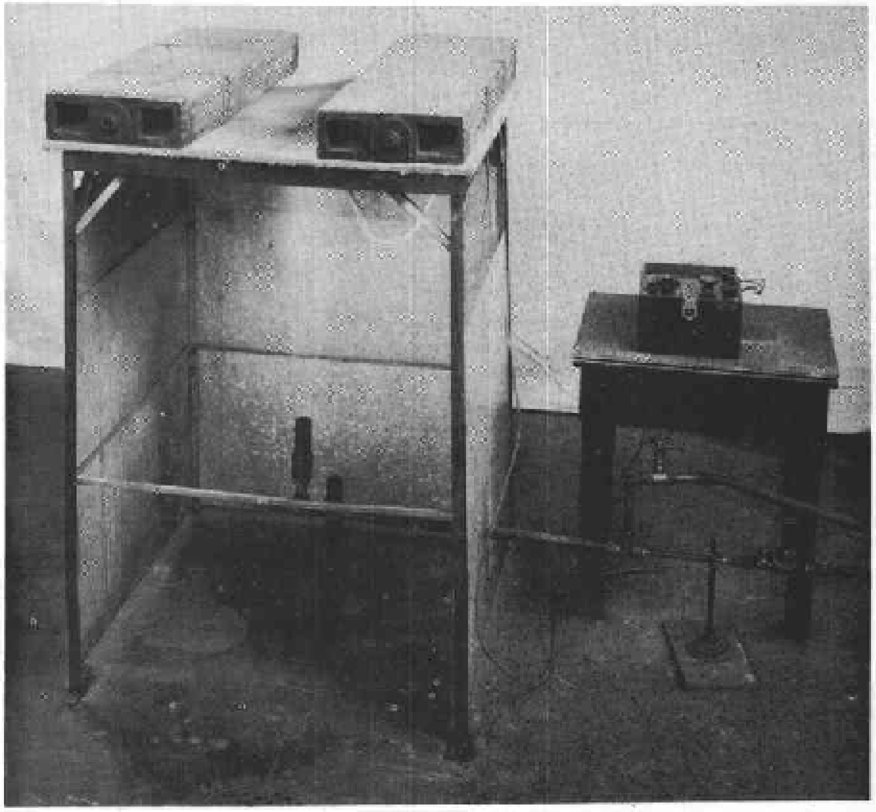


Figure 12. --U. S. Federal Specification fire test method for prefabricated acoustical units. Horizontal panel test for flame spread and combustibility classification. (U. S. Federal Specification SS-A-118a.)

Z M 90870 F

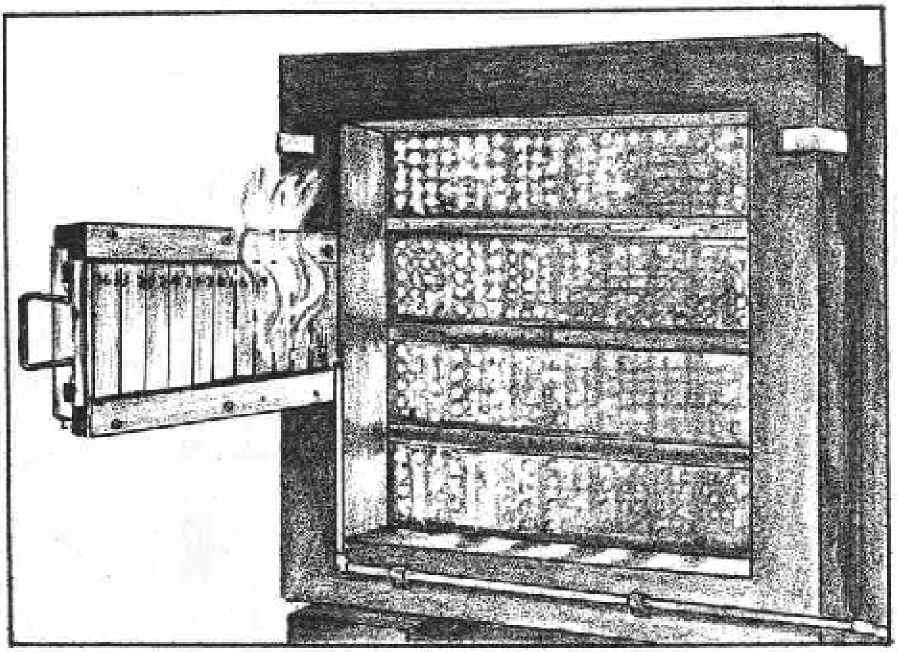


Figure 13. --Apparatus for British Standard flame spread test with radiation of varying intensity. (Sketched from photograph in British Standard BS 476: 1953.)

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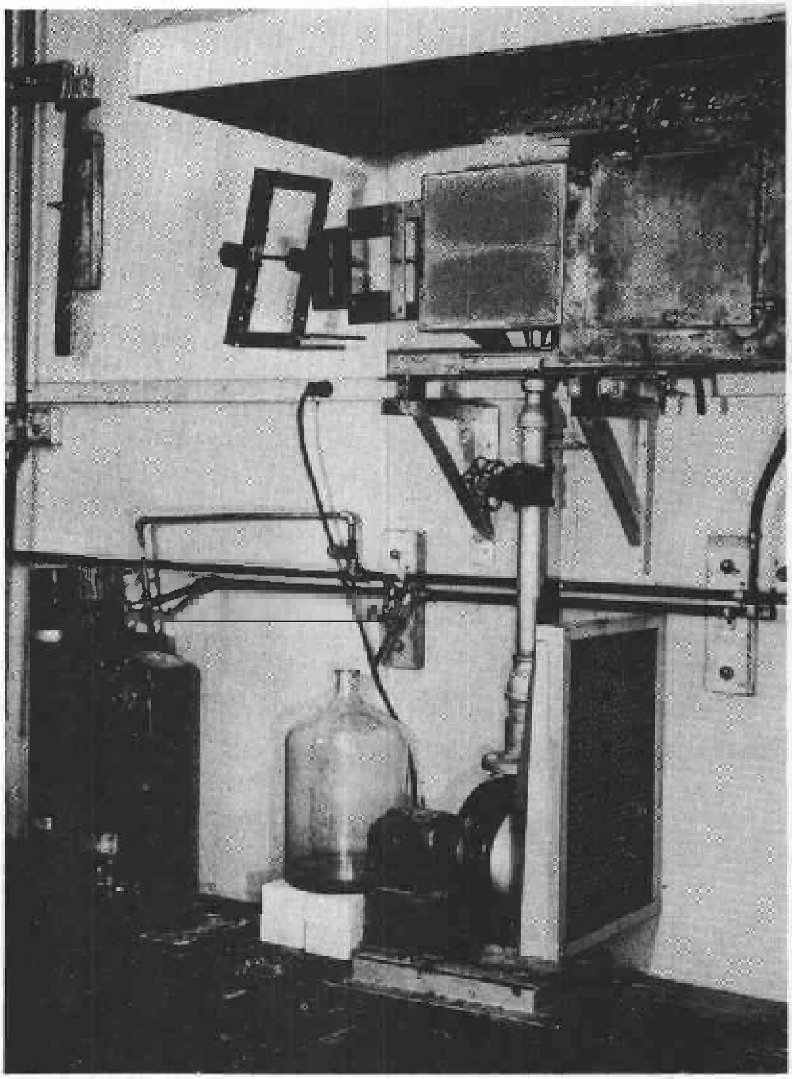

Figure 14. --General arrangement of apparatus for radiant panel flame test under development as a modification of the British Standard method. (Photograph courtesy U. S. National Bureau of Standards.)

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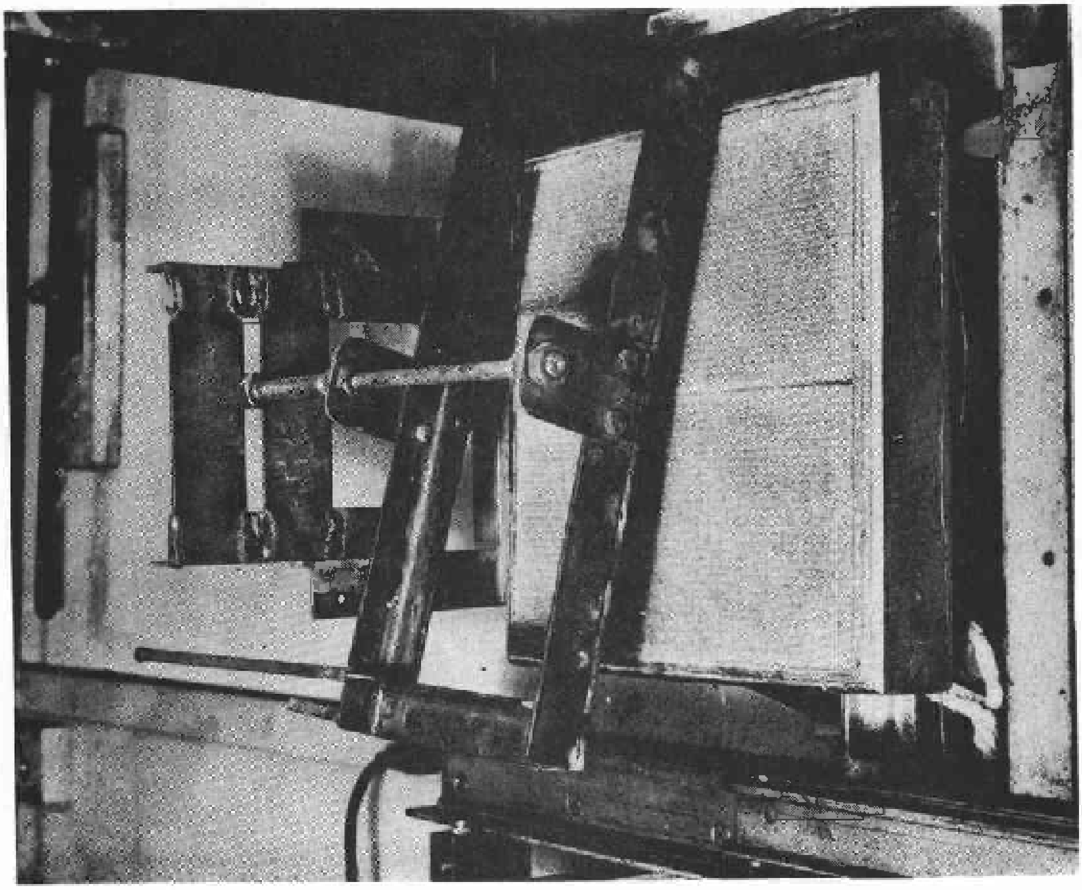

Figure 15. --Radiating surface and specimen holder for radiant panel flame test under development as a modification of the British Standard method. (Photograph courtesy U. S. National Bureau of Standards.)

Z M 95674 F

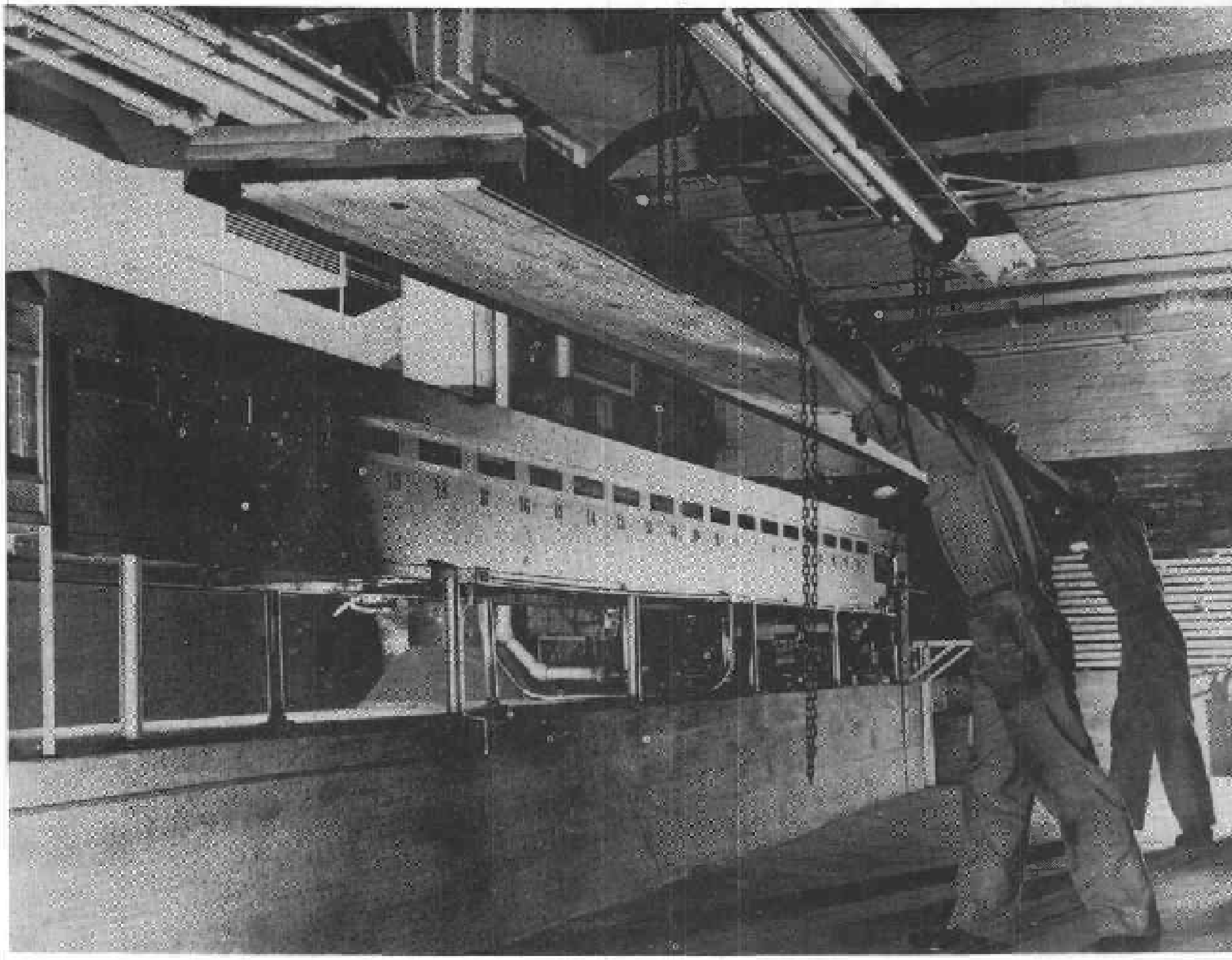

Figure 16. --ASTM Standard large-scale tunnel test for fire hazard classification of building materials. Horizontal furnace for flame spread tests. (ASTM Standard E 84-50T.) (Photograph courtesy of Underwriters' Laboratories, Inc.)

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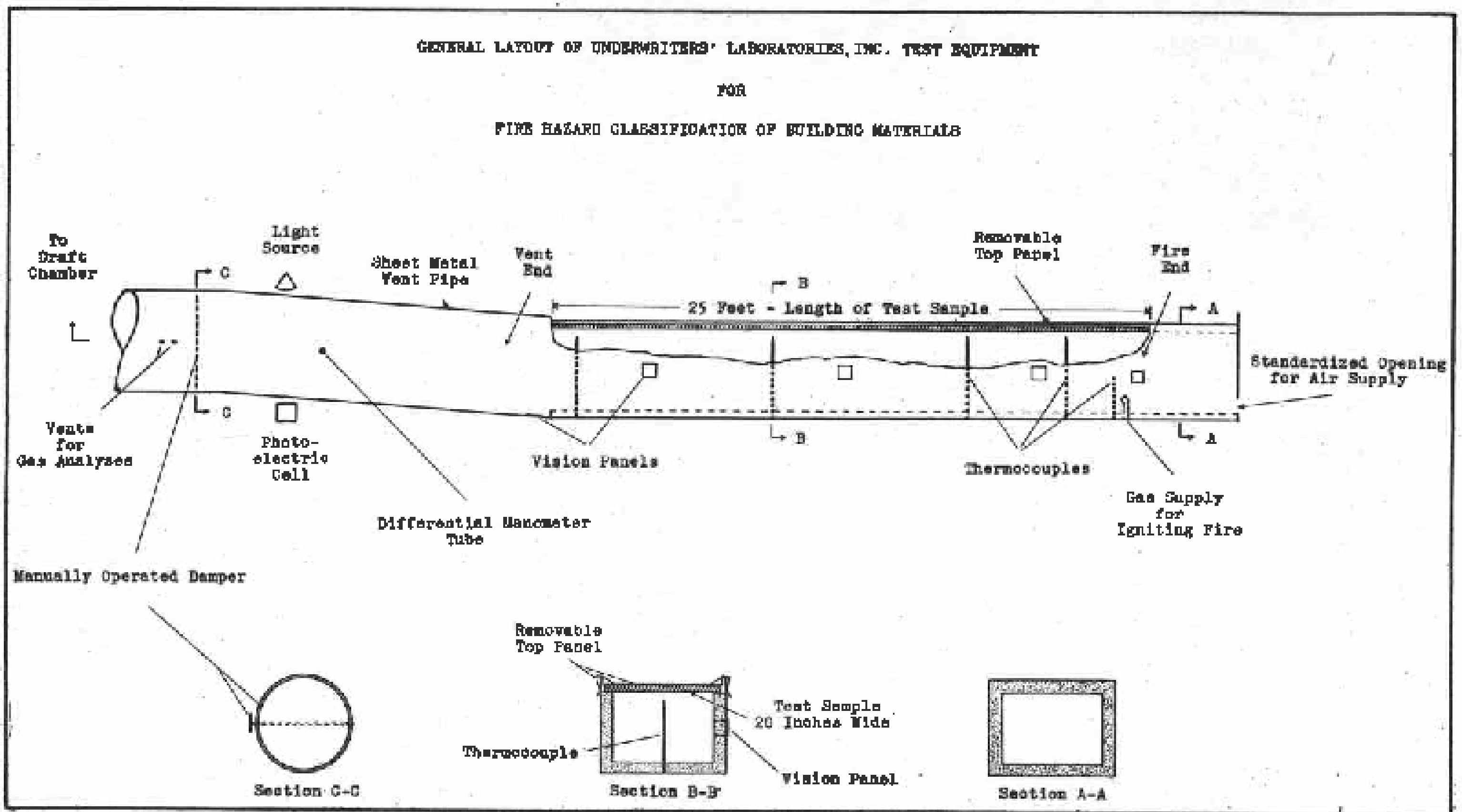

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Figure 17. --Details of horizontal furnace for flame spread tests. (ASTM Standard E 84-50T). (Photograph from Bulletin of Research No. 32, Underwriters' Laboratories, Inc.)

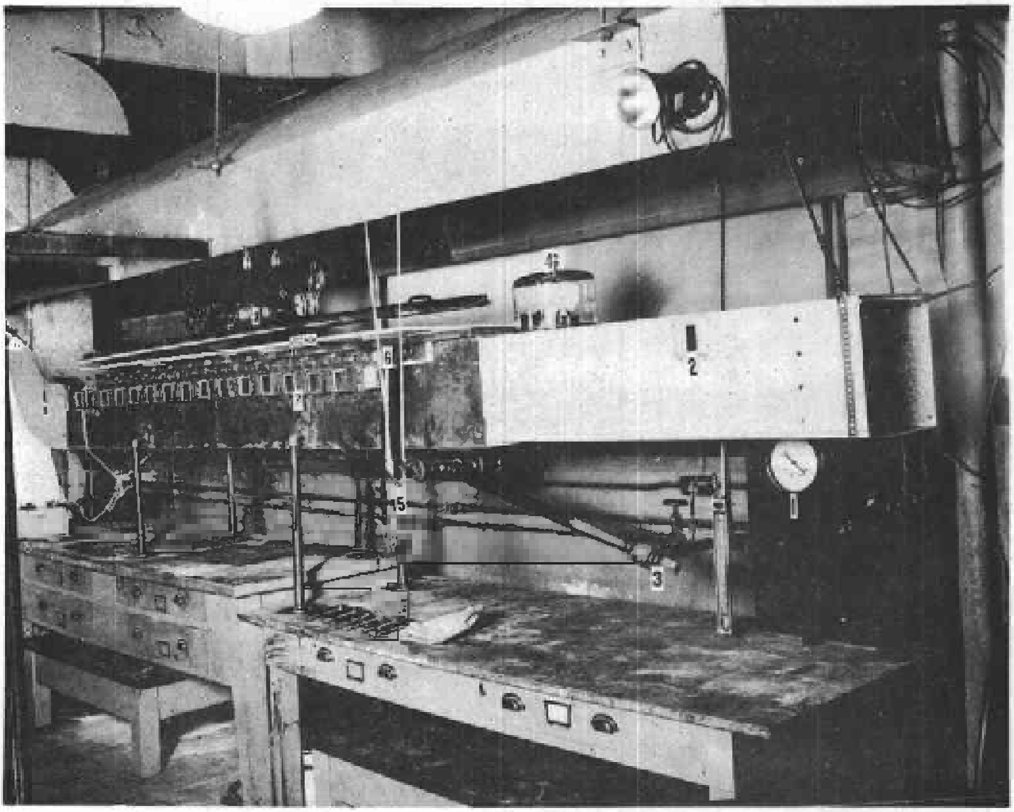


Figure 18. --Small scale tunnel test for fire hazard classification of building materials. Forest Products Laboratory horizontal furnace for flame spread tests.

Z M 87965 F

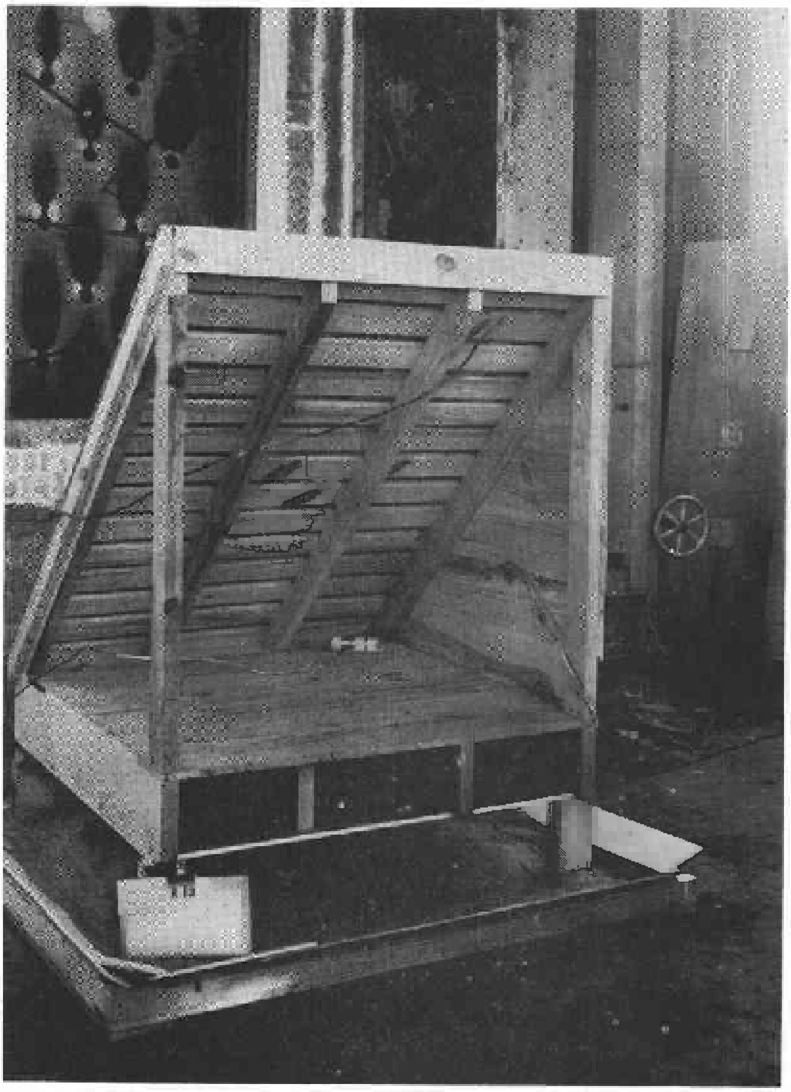


Figure 19. --Roof-corner flame spread test. Ignition is by magnesium bomb.

Z M 40056 F

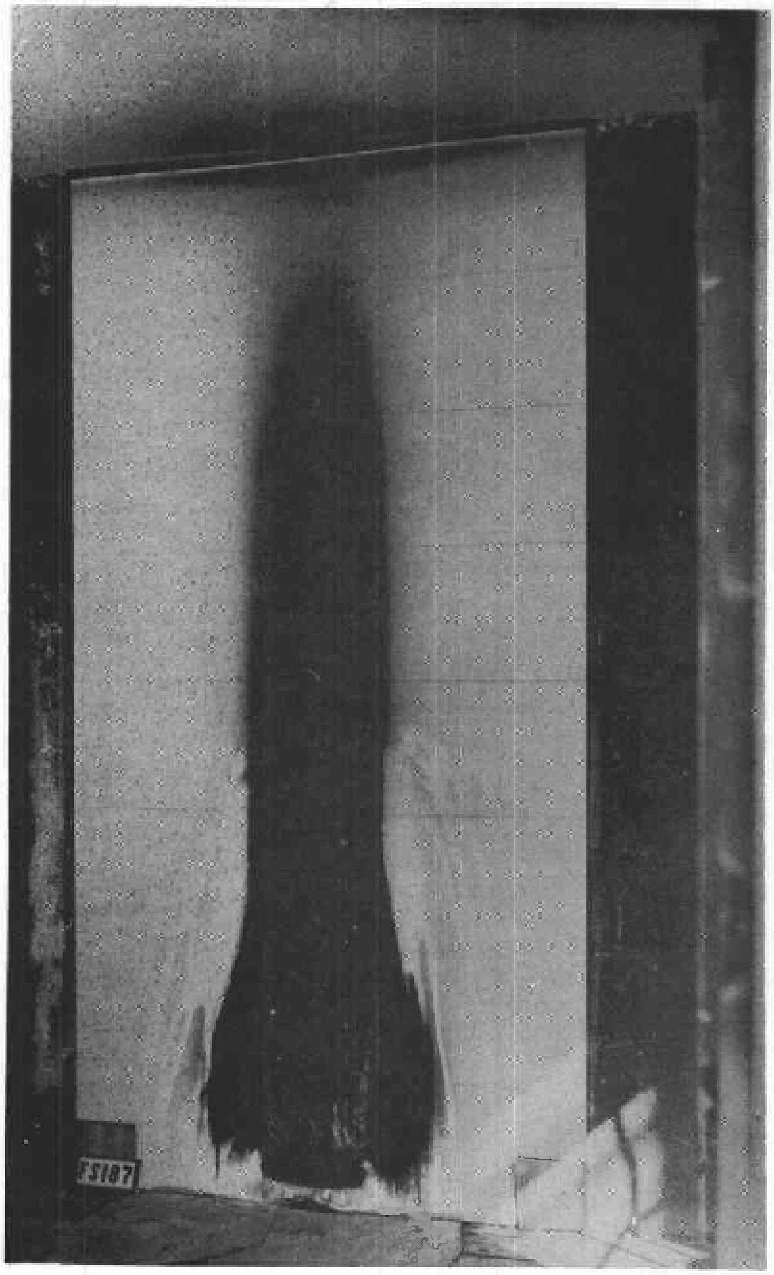


Figure 20. --Side wall flame spread test. Ignition is by wood crib.

Z M 88605 F

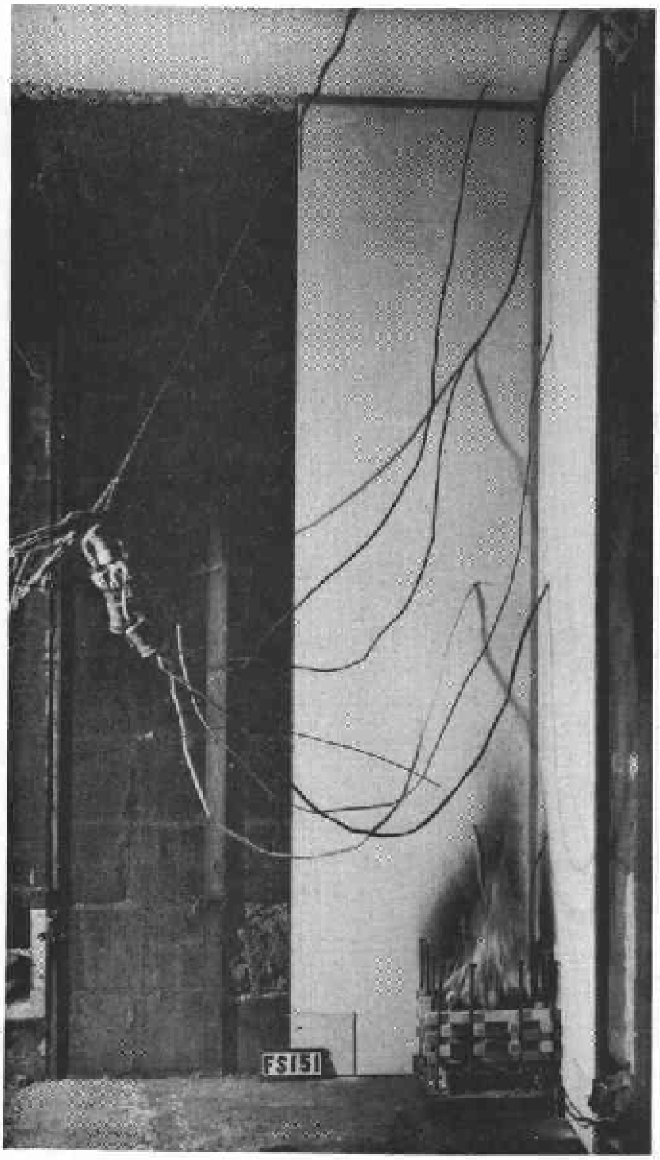


Figure 21. --Corner-wall flame spread test. Ignition is by wood crib.

Z M 98960 F

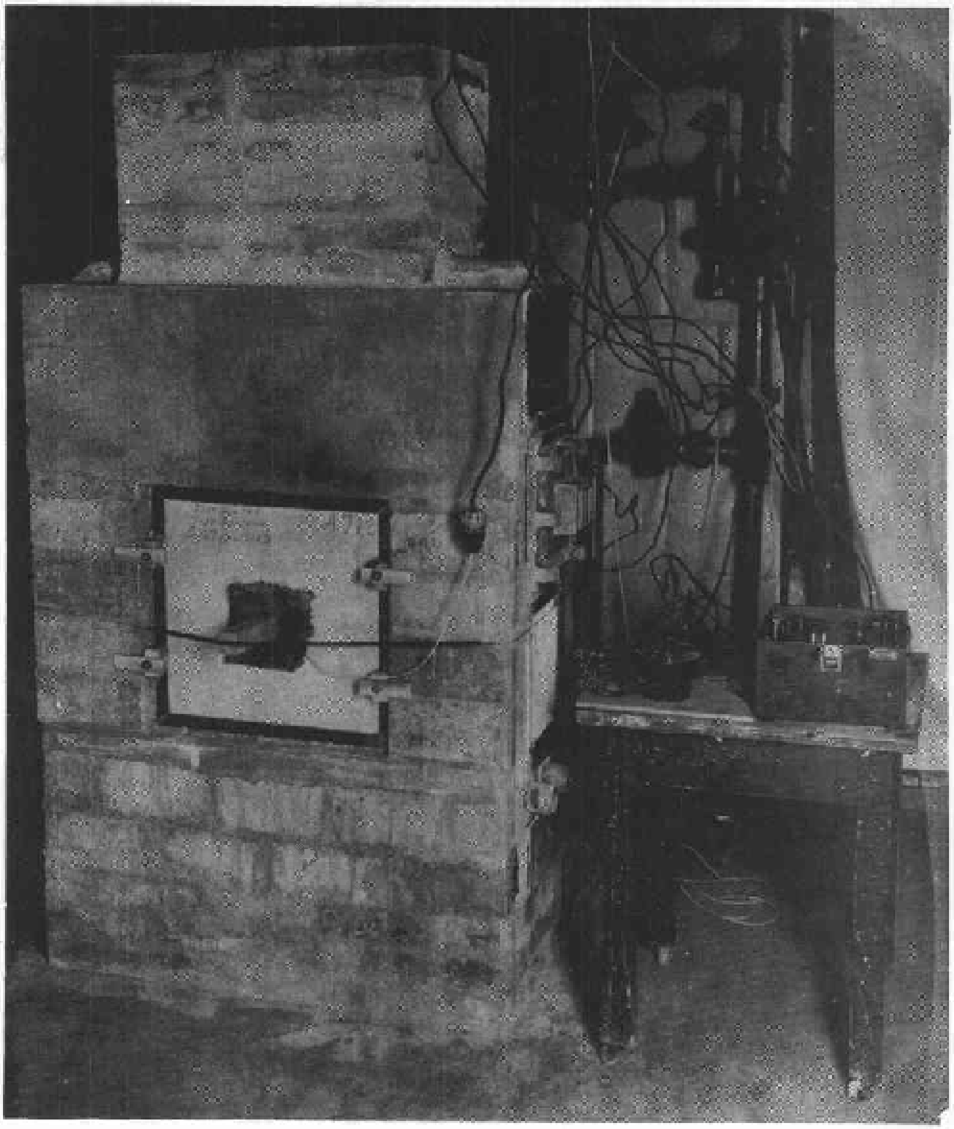


Figure 22. --Small (20- by 20-inch) vertical furnace for fire penetration tests. Ignition is by gas burners.

Z M 86784 F

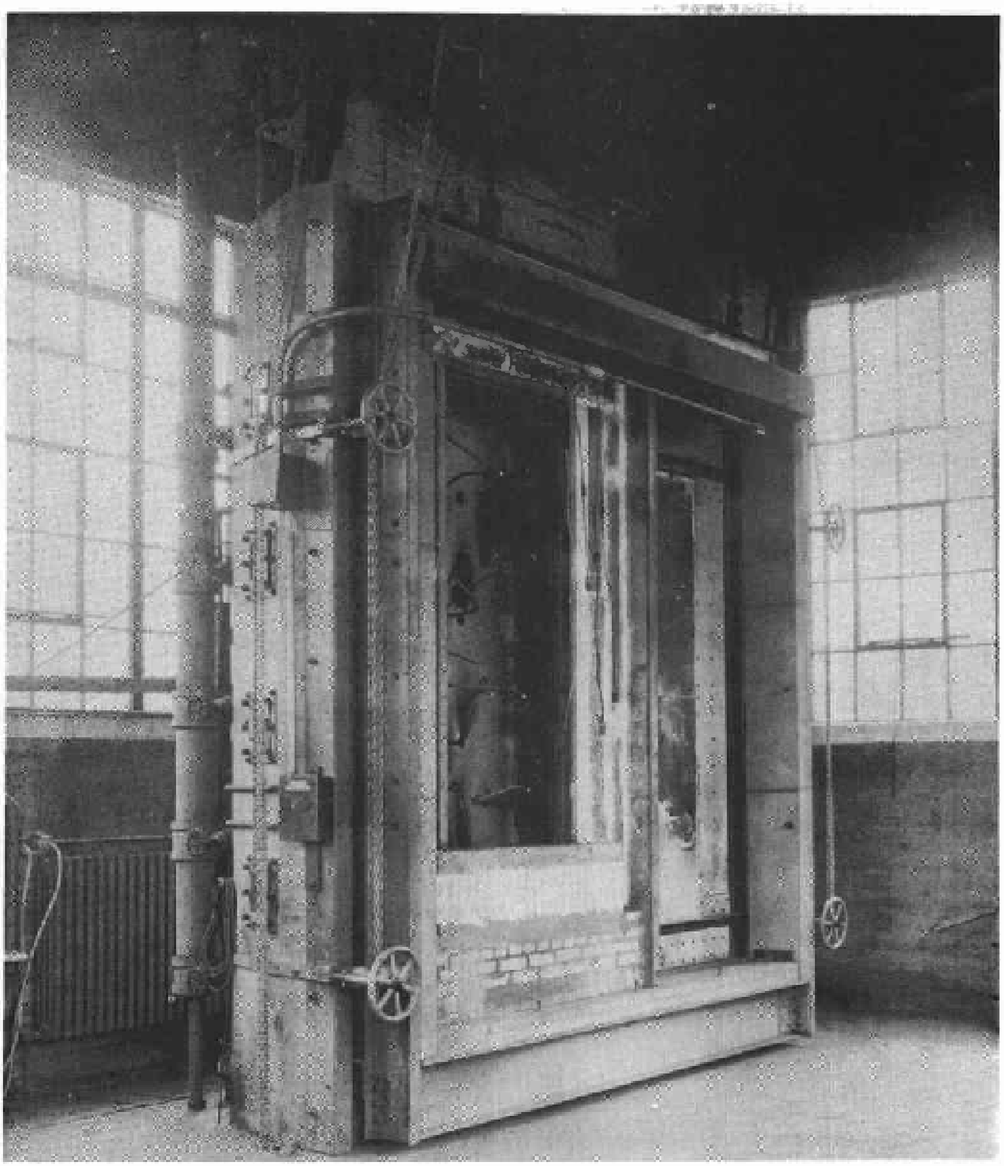


Figure 23. --Large (10- by 10-foot) vertical furnace for fire penetration tests. Ignition is by gas burners.

Z M 46920 F

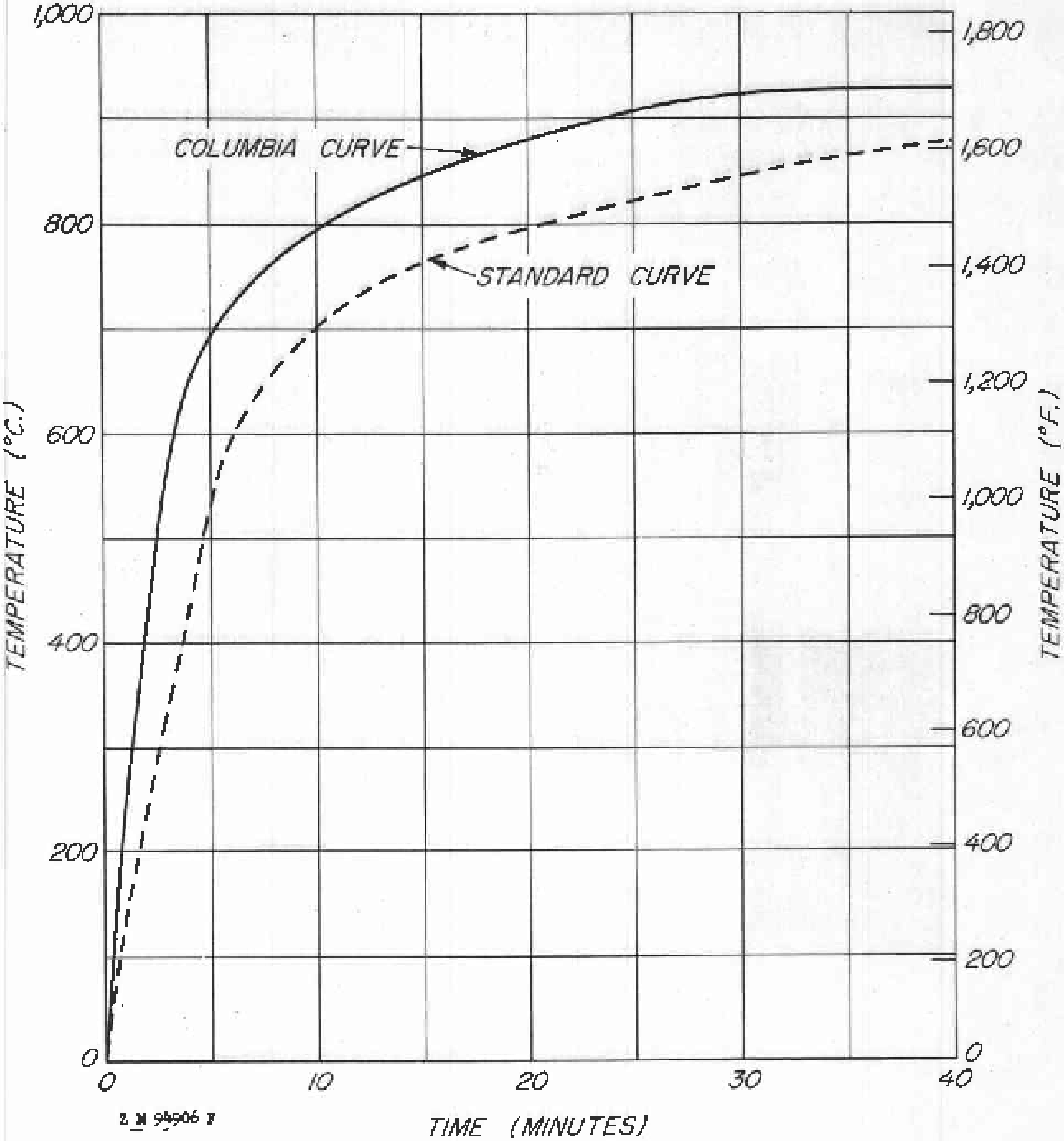


Figure 24. --Time-temperature curves for fire penetration tests.

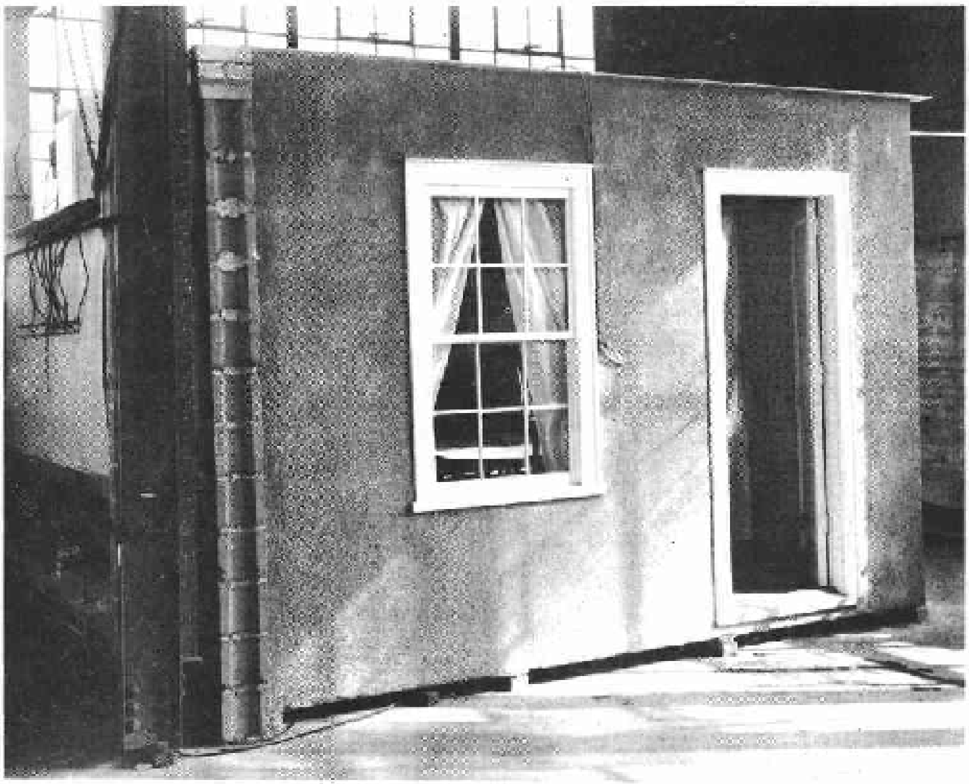
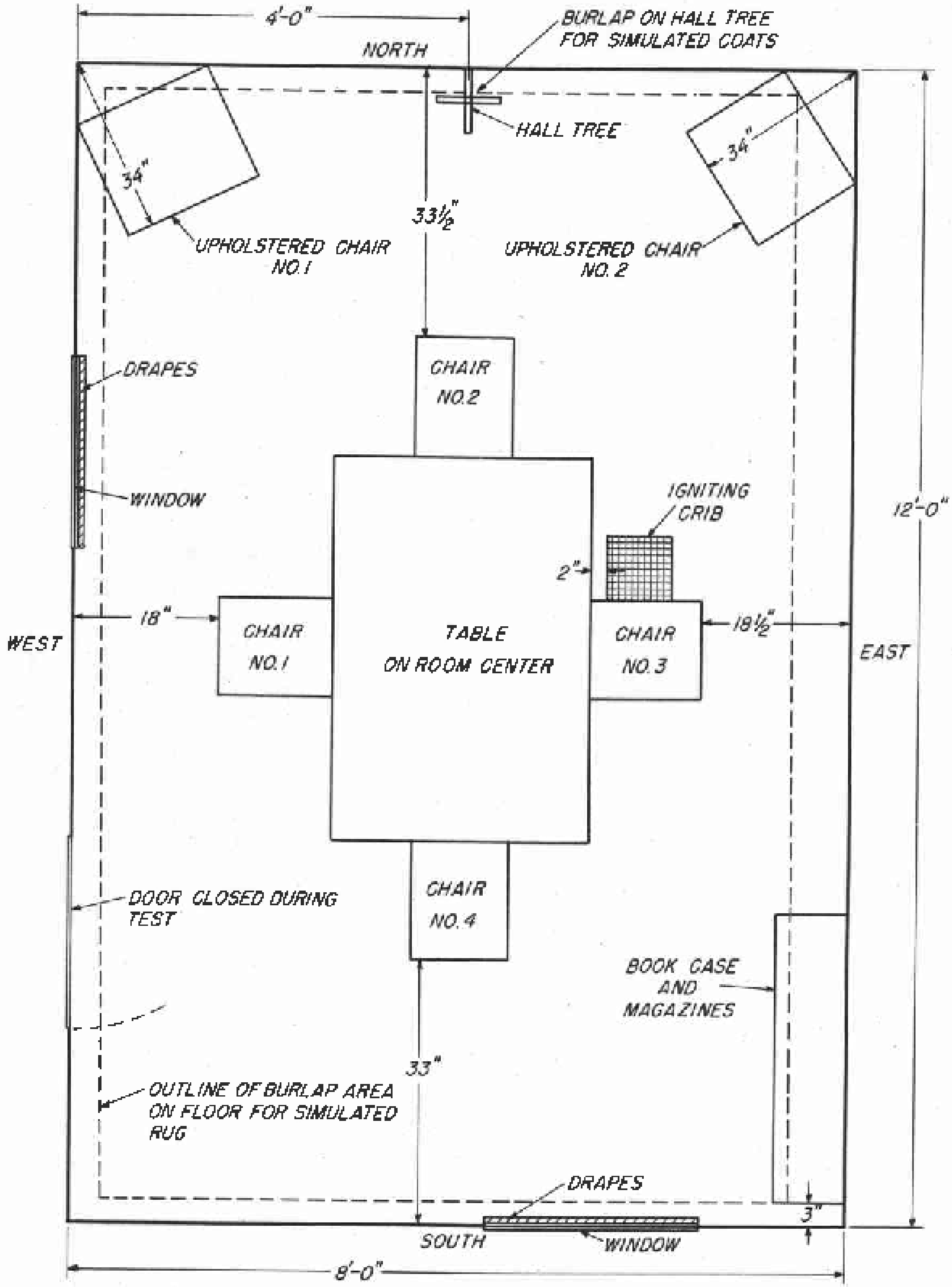


Figure 25. --Dwelling room burn-out test. Exterior view, of room prior to test.

ZM 76705 F

Figure 26. --Dwelling room burn-out test. Interior view showing mock-up furniture used.

ZM 80526 F



ZM 81118 F

Figure 27. --Dwelling room burn-out test. Diagram of furniture arrangement in room.

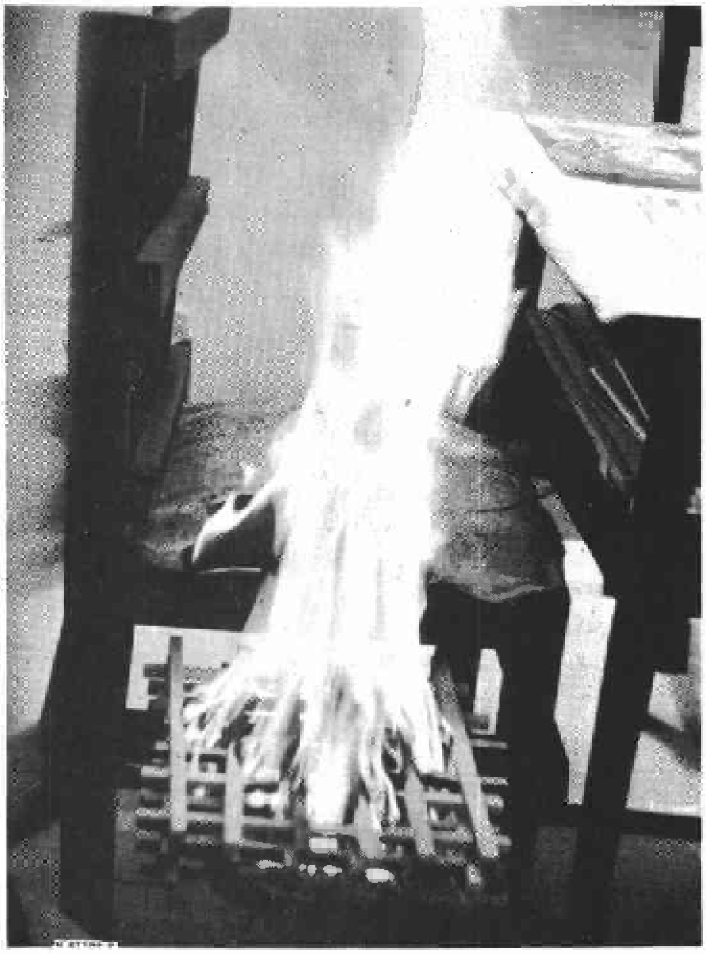


Figure 28. --Dwelling room burn-out test. Interior view showing flame spreading to simulated furniture from igniting crib.

ZM 81102 F