SURFACE FLAMMABILITY MEASUREMENTS FOR BUILDING MATERIALS AND RELATED PRODUCTS

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I. INTRODUCTION

Building codes, specifications, and other standards in use throughout the United States and many other countries set limits of acceptability for the surface flammability of combustible materials used for purposes where
protection of life from fire must be considered. One of the largest areas so regulated is the interior finishes, including wall paneling, trim, and ceiling surfaces, used for institutional, educational, assembly, and other public buildings. Typical regulations (26,34,38,40,47) are generally most restrictive with respect to the exit corridors and stairway enclosures in order to ensure safe exit for people during a fire. It must be recognized, however, that incomplete burning of contents can produce unburned combustible gases, resulting in spread of fire to remote areas of buildings without involving flame spread over interior finish surfaces.

Regulations for flammability may also apply to certain interior furnishings, such as curtains, light diffusers, movable partitions, and decorations used in institutional and public assembly buildings.

Most of the test methods that have been developed for classifying the fire hazard of materials are based on the rate of flame travel over their surfaces under prescribed fire exposure conditions. The heat contribution and obscuration of a light source by the smoke developed by burning may also be measured as a part of the test procedure. The ignition characteristics of building materials usually are not regulated, but the flame-spread characteristics of a product depend on ignition characteristics, heat contribution, and thermal characteristics.

Some of the tests that have been developed for measuring these related characteristics of smoke development, heat release, and ignition are not described in detail in this chapter, but include the following:

**Smoke Development**
- Rohm and Haas XP-2 smoke density chamber (42a)
- National Bureau of Standards smoke chamber (36a)

**Heat Release**
- Ohio State calorimeter (46a)
- National Bureau of Standards calorimeter (41a)
- Forest Products Laboratory rate of heat release furnace (21a)

**Ignition**
- Setchkin ignition test (13a)
- Noncombustibility test, ASTM E136 (15b)
- Fenimore–Martin limiting oxygen index (34a)
- Roof Covering (15a)—involves ignition by various size wood brands
- Methenamine pill test for floor coverings (13b)

Most of the flame-spread test methods are empirical in nature because it is very difficult to simulate by a single test method the variety of conditions present in fires. There is believed to be a serious disparity between the performance of materials in actual fires and the results of some of these small-scale tests. For example, certain plastic foam materials were judged to be of
low flammability based on the results of certain small-scale tests. However, in actual experience or by observed performance in room corner wall-ceiling research (64a) ignition and flame spread were found to be rapid. As a result the Federal Trade Commission (28a) has cited many plastic foam manufacturers for advertising fire performance based on the small-scale results. There has been considerable emphasis recently on development of the room corner wall-ceiling tests or modification of other flammability tests to better reflect the performance of plastic foam materials. The American Society for Testing and Materials has also established a committee (la) to select and develop test methods for materials to better represent the potential hazard under actual fire conditions.

There have been some limited attempts to relate thermal and kinetic parameters to the burning process of solids and spread of fire (1,21,32,36, 46,48). Gaydon and Wolfhard have also prepared an excellent book, *Flames, Their Structure, Radiation, and Temperature*, which includes discussion of the theories of flaming processes (29).

This chapter is primarily limited to surface flammability measurements as applied to building materials and closely allied solid products. However, there are also fire-hazard regulations that apply to the transportation, storage, and use of certain liquids and gases. The fire-hazard classifications for these materials are based chiefly on flash point, ignition, temperature, and lower and upper flammability limits. The techniques for the measurement of the fire hazard and related properties of many flammable gases and liquids are given in the National Fire Protection Association (NFPA) *Fire Protection Handbook* (39).

II. FLAMMABILITY TEST METHODS FOR BUILDING MATERIALS

The Steiner or 25-ft tunnel furnace method (ASTM Standard E84-70), as developed by the Underwriters’ Laboratories, has the widest acceptance by code and insurance authorities as a rating method for measuring surface flammability of building materials. Three other methods, namely, the National Bureau of Standards radiant-panel method, the Forest Products Laboratory 8-ft tunnel method, and the Factory Mutual calorimeter furnace method, have recently been developed and have attained fairly wide usage, particularly for research and development investigations. Other test methods that have been used in specifications and standards in the past and methods that have been limited primarily to research and development purposes include the fire-tube, crib, modified Schlyter, SS-A-118b acoustical tile, fiberboard inclined-panel, and the FPL room corner wall-ceiling tests.
The spread-of-flame and fire propagation (building board) methods developed in England are the better known of the foreign test methods. The reproducibility of these various test methods for measuring surface flammability is generally good, once they have passed the development stage and the known parameters can be controlled. The correlation of one method with another presents greater difficulty. The methods generally rank products in the same order, but the actual numerical values and spread of values may differ considerably. This ranking correlation is generally best if a homogeneous product is involved with only minor variations in treatments. However, when composites having highly flammable facings and a core of low flammability, or vice versa, are evaluated, the various methods may even rank the order of products quite differently. Wilson (65) has developed an approximate relationship between several of the flammability methods as shown in Fig. 1. A very limited amount of work has been done to relate the performance of laboratory tests to full-scale fire tests. The U.S. Forest Products Laboratory found that there was good correlation between the results of a corner wall-ceiling test within an 8-ft room and 8-ft tunnel furnace results for a variety of homogeneous wood-base products (42).

Tests of the propagation of fire along ceiling materials were made (37) in corridors at the St. Agnes and Sante Fe High Schools, Los Angeles, Calif., and the results were compared with those obtained on the same materials by several laboratory flammability test methods. An analysis by Reichman (43) gives the correlation coefficient between the laboratory results and the spread of fire along the corridor in these tests as 0.83, 0.96, 0.90, and 0.63, for the 25-ft tunnel, 8-ft tunnel, radiant-panel furnace, and inclined-panel methods, respectively.

The Forest Products Laboratory also conducted a series of burnout tests (45a) in a 70-ft school corridor with plaster, red oak lumber, and hardboard wall coverings. The excess unburned gases that developed from the wood crib contents resulted in flashover along the entire corridor prior to appreciable spread of fire along any of the wall coverings. This indicates that flashover of gases can often be a more dominating factor in the spread of fire than flame spread along interior finish surfaces.

A. STEINER TUNNEL OR 25-FT TUNNEL FURNACE METHOD (ASTM STANDARD METHOD E84-70)

The 25-ft tunnel furnace method was developed at the Underwriters’ Laboratories, Inc., Chicago, Ill., under the supervision of A. J. Steiner, for whom the tunnel method has been named. This method is probably the best known of the currently used tests for measuring surface flammability characteristics of building materials. It became a standard procedure of the Underwriters’ Laboratories about 1944 and a tentative standard of
ASTM in 1950, and was adopted as a full ASTM standard in 1961 (15). In addition to recognition by ASTM, the method has been adopted as Standard No. 255 of the National Fire Protection Association. The fire-hazard classifications of building materials by model building codes and many local codes are based on this method.

Furnaces of this type for the fire-hazard classification of building materials are available at several laboratories, including the Underwriters’ Laboratories Inc. at both Northbrook, Ill., and Santa Clara, Calif.; the Southwest Research Institute, San Antonio, Tex.; and the Underwriters’ Laboratories of Canada, at Scarborough, Ontario, Canada. Both the Underwriters’ Laboratories, Inc. and Underwriters’ Laboratories of Canada provide information on commercial products which they have evaluated by this method (51,53). Several manufacturing companies also have installed this type of furnace in their own research laboratories for the fire-hazard classification of their building products.

1. Apparatus and Specimen

The furnace is a 25-ft horizontal tunnel (Figs. 2 and 3), providing an insulated inner chamber, 18 in. wide by 12 in. deep, extending the length of the furnace. The air inlet and a gas burner with two ports for heating the furnace are located at one end and the exhaust flue at the other. Pressure measurement devices, control devices, and a light source and photoelectric cell for smoke-density measurement are provided at the vent end of the furnace.

The test specimen, 20 in. wide by 25 ft long, is attached to the underside of the cover or supported on the furnace ledges, so that when the cover is placed in position an 18-in. width of the specimen is exposed as the ceiling of the tunnel furnace. A sand or liquid seal along the edges of the cover reduces air leakage along the length of the furnace. Glass windows are located along the sides of the tunnel to permit observation of flame progress during the test. Thermocouple junctions are mounted in the furnace floor 14 ft from the fire end of the specimen and also 1 in. below the exposed surface of the test specimen, 1 ft from the vent end. A forced-draft system in the exhaust flue, controlled by manual and automatic draft regulators, maintains a constant draft pressure throughout the test.

2. Calibration

The tunnel furnace is operated first with a ¼-in., asbestos-cement board specimen in place to check for excessive air leakage, air velocity, and heating conditions. The test is performed for 10 min with the gas supply adjusted to
approximately 5000 Btu/min. Thermocouple readings of temperatures at the vent end of the furnace are recorded and compared with standard preheat curves.

When conditions have been standardized, the test is performed with select red oak flooring as the sample. Observations are made of the time required for the flames to reach the end of the specimen. Temperatures, measured by the thermocouple near the vent end of the furnace, and the smoke-density
photocell output are recorded continuously throughout the test. Under proper operation, the flames should reach the end of the red oak specimen in 5.5 min ± 15 sec.

3. Procedure

Following the standardization of the equipment based on the asbestos-cement board and red oak standards, sample materials are installed in proper position and tested. The cover is then placed on top of the furnace. Floor temperatures of the furnace are adjusted to 105°F ± 5 prior to test. The draft condition within the tunnel is adjusted to approximately 0.075 in. of water as indicated on a differential manometer tube, the same as used in the standardization tests. This pressure differential results in an average air velocity of approximately 240 ft/min at the vent end of the furnace.

The gas burner is then ignited and, under normal operating conditions, the ignition fire extends for approximately 4½ ft along the specimen; thus the distance from the end of the ignition flame to the end of the test specimen is about 19½ ft.

The test is continued for 10 min at the same heating rate and induced draft condition, unless the specimen is entirely consumed in the fire in less time. The time required for the flames to reach the end of the test specimen
is noted, and readings of the photoelectric cell output and end thermocouple are taken throughout the test.

4. Calculations

a. Flame Spread

The flame-spread classification for materials depends on the time required for the flames to spread the 19½-ft exposed length of the test specimen; it is calculated as follows:

1. If the time required is 5½ min or less,

   \[
   \text{flame-spread classification} = \frac{5.5 \text{min} \times 100}{\text{time (min) to travel the length of specimen}}
   \]

2. If the time is more than 5½ min but less than 10 min,

   \[
   \text{flame-spread classification} = \frac{1}{2} \left( 100 + \frac{5.5 \text{ min} \times 100}{\text{time (min) to travel length of specimen}} \right)
   \]

3. If the time required is more than 10 min,

   \[
   \text{flame-spread classification} = \frac{\text{distance (ft) flames travel over specimen} \times 100}{19.5 \text{ ft}}
   \]

4. If the distance traveled in 10 min is more than 13.5 ft and less than 19.5 ft,

   \[
   \text{flame-spread classification} = 50 + [1.41 \times \text{distance (ft) flames travel}]
   \]

Changes in these methods of calculation are being made by ASTM Committee E-5, so that flame-spread values over the entire range will relate more uniformly to the average rate of flame travel.

b. Fuel Contribution

The time-temperature data for the sample, asbestos-cement board, and red oak specimens are plotted on similar coordinates, and the areas under the respective curves are used in computing the fuel-contribution classification as follows:

\[
\text{Fuel-contribution classification} = \frac{(\text{area under sample curve}) - (\text{area under asbestos board curve})}{(\text{area under red oak standard curve}) - (\text{area under asbestos board curve})} \times 100
\]
c. **Smoke Density**

The time–photocell output data for the sample, asbestos-cement board, and red oak specimens are plotted on similar coordinates. The average areas under the respective curves are then used in computing the smoke-density classification in the same manner as for the fuel-contribution classification.

### B. Radiant-Panel Method  
(ASM Standard Method E162-67, Reapproved 1973)

Following the acceptance of the 25-ft tunnel furnace method E84 (15) by ASTM in 1950 as a tentative method for measuring surface flammability of building materials, development of a simpler laboratory-scale method was started by the National Bureau of Standards. The radiant-panel method, which was developed as a result of their work, has now been made ASTM Standard E162 (17). This method is also an Interim Federal Standard No. 00136b (Comm-NBS) (62), and has been accepted in several government specifications as an alternative to the 25-ft tunnel furnace test method. The National Bureau of Standards has used this method in several research studies on surface flammability (30,31,32,44,45), and more than 20 of these installations are in use in research and development laboratories. This test has been found suitable for evaluating materials in the form of boards, sheets, structural members, heavy fabrics, and finish materials applied as liquids, films, or sheets.

#### 1. Apparatus and Specimen

In this method, a 6- by 18-in. panel specimen is mounted within a specimen holder, inclined at an angle of 30° and facing toward a vertical radiant panel, as shown in Figs. 4 and 5. The upper 6-in.-wide edge of the specimen is located 4¾ in. from the radiant panel.

The radiant panel consists of porous, refracting material mounted within a cast-iron frame, 13 by 19 in. in overall dimensions, and heated by a gas–air mixture. The radiant panel is equipped with venturi-type air–gas mixer, blower, control, and regulating valves to facilitate operation at temperatures up to 1500°F (816°C).

A hood and stack, located above the specimen, exhaust the products of combustion and are used for mounting of chromel–alumel thermocouples and smoke-sampling equipment. A small pilot burner of ⅛-bu. stainless steel tubing (⅛-in. OD) is located horizontally so that a 2-3-in. flame of gas, premixed with air, will emit from the burner tip near the top edge of the panel specimen.
2. Procedure

For the test, the gas–air mixture is passed through the radiant panel and burned for 30 min, then adjusted to maintain a heat output equivalent to a black body at a temperature of 1238°F ± 7 (670°C ± 4) as measured by a radiation pyrometer. The hood and auxiliary blower are adjusted to produce a velocity of 250 ft/min at the top of the stack when the radiant panel is at the standard temperature.

The pilot burner is ignited, adjusted to give a 2–3-in. flame, and positioned in front of the radiant panel so as to touch or be within ½ in. of touching the center of the top edge of the test panel when placed in test position. The test panel within the specimen frame, suitably backed with ½-in. asbestos millboard if ≤5 in. thick, is then moved into exposure position. The specimen is exposed to the radiant heat and pilot flame for 15 min or until the flame front has progressed down the full length of the panel. The time for the flame front to progress every 3 in. on the face of the specimen and the maximum temperature rise of the stack thermocouples are recorded.
3. Smoke Deposit

A smoke-sampling device of the type shown in Fig. 6 is located at the top of the stack during the test. Smoke is withdrawn using an aspirator or pump capable of maintaining a flow velocity equivalent to 40 ft/min (20.4 cm/sec) of air at 70°F (21°C) at the exposed face of the preweighed filter disk.

4. Calculations

The flame-spread index is the product of flame-spread factor, $F_s$, and the heat evaluation factor, $Q$, where

$$F_s = 1 + \frac{1}{t_3 - t_5} + \frac{1}{t_6 - t_9} + \frac{1}{t_{12} - t_9} + \frac{1}{t_{15} - t_{12}}$$

$[t_1, \ldots, t_{15} =$ time (min) from the start of the test for the flame front to arrive at a position 3, \ldots, 15 in., respectively, along the length of the specimen]
The constant 0.1 was selected so that the range of flame-spread index values would approximate those obtained in the 25-ft tunnel furnace (ASTM E84) method.

For the smoke-deposit value, the glass-fiber filter paper of the sampling device is reweighed to the nearest 0.0001 g and corrections are made for the
loss of moisture during the test period. For low smoke deposits, the optical density of the sampling disk is measured with a transmission densitometer and compared with that of the clear peripheral area of the disk.

**C. FOREST PRODUCTS LABORATORY’S 8-FT TUNNEL FURNACE METHOD**

**(ASTM STANDARD METHOD E286-69)**

The development of the 8-ft tunnel furnace was started at the U.S. Forest Products Laboratory (FPL) in 1951. The 25-ft tunnel furnace method had just been made a tentative ASTM Method E84 for measuring surface flammability, and there was considerable interest in developing a smaller-scale test, which would have special application for research and development work. This development was initiated in cooperation with the Housing and Home Finance Agency, and later supported through a number of associations cooperating through ASTM Committee E-5 on Fire Test of Materials and Constructions.

It was the original intent to develop a small-scale furnace for an 8-ft specimen utilizing the general principles of the 25-ft tunnel furnace. As a result of tests with three models of the furnace, it was found necessary to make several major modifications in order to obtain proper definition of the flame front when operating under high heat flux with a short length of specimen.

The current furnace, completed in 1957 (24), has been used extensively for determining the flammability of various wood-base products, coatings, and other materials (24,25,27,42). The method is described in the ASTM Proceedings of 1960 (3) and has been approved as ASTM Method E286-69 (17a). Ten of these furnaces are in operation in research and development laboratories, and correlation tests have been run among four of the furnaces (28).

**1. Apparatus and Specimen**

The apparatus consists of a gas-heated tunnel furnace (Figs. 7-9) about 10½ ft long to accommodate a test panel specimen, 13¾ in. by 8 ft. The furnace has essentially three main compartments—an 8- by 16½-in. lower firebox, 10½ ft long, extending the entire length of the furnace (Figs. 7 and 8); the specimen combustion chamber just above the partition plate of the firebox (item 7, Fig. 8); and the upper hood and stack system (items 11 and 12, Fig. 8). The furnace slopes 6° from end to end so that tests can be run under natural draft conditions. Complete detailed drawings are available from the
Fig. 7. View of 8-ft tunnel furnace from observer's side, showing (1) gas supply; (2) ignition burner manometer; (3) air inlets; (4) observation holes; (5) hood to collect combustion gases; and (6) photoelectric cell on furnace stack.

U.S. Forest Products Laboratory or the American Society for Testing Materials.

The lower firebox is constructed of 12-gage low-carbon steel sheet on the two sides and bottom, and 12-gage, type-310 stainless steel sheet in the shape of an inverted U as the top. The inside of this firebox tunnel is lined on the sides and bottom with 1-in. asbestos millboard.

The specimen chamber is located above the steel top of the firebox (item 7, Fig. 8). It consists of an angle-iron frame and enclosure of 12-gage steel sheet and 1-in. millboard as shown in Fig. 8. The angle-iron frame (items 4 and 5, Fig. 8) is positioned so that the specimen will rest at an angle of 30° to the upper surface of the firebox with the lower edge of the specimen 1 in. above the stainless steel plate. There is a 1½-in.-wide slot (item 5, Fig. 8) extending the length of the chamber between the upper edge of the angle-iron frame and the wall of the chamber for the escape of the combustion products into the hood. The combustion chamber is also provided with a series of air inlet openings (item 3, Fig. 7) and observation holes (item 4, Fig. 7) along its entire length.
Fig. 8. View of 8-ft tunnel furnace from specimen side, showing (1) gas supply to main burner; (2) ignition burner manometer; (3) ignition burner; (4, 5) angle-iron frame for support of specimen; (6) holes in partition plate; (7) partition plate between firebox and combustion chamber; (8) observation holes; (9) air inlets; (10) specimen cover; (11) hood to collect combustion gases, and (12), (13) light source and photoelectric cell.

A series of holes (item 6, Fig. 8) are located in the partitioning plate to provide some turbulence in the specimen combustion chamber, resulting in more uniform burning of products. A cover (item 10, Fig. 8) is also provided to be placed over the back of the specimen during test.

The heat is supplied within the furnace by using the main burner (item 1, Fig. 7), which is 1¼-in., T-head iron pipe, drilled with two parallel rows (90° apart) of ⅛-in.-diameter holes spaced at ½-in. distances. Air and gas are supplied to the pipe through a suitable, atmospheric injector type air-gas mixing unit.

Pilot-flame ignition is supplied within the combustion chamber by a small pipe burner (item 3, Fig. 8). The pipe burner is an 8½-in. length of ⅜-in.-diameter iron pipe which has been drilled with 6⅛-in.-diameter holes spaced 1 in. apart. This burner is located ½ in. below and parallel to the face of the test.
panel, and is 1 in. from the lower end of the specimen. Gas to this burner is metered through a small flow manometer (item 2, Figs. 7 and 8).

Auxiliary equipment used for measuring heat contribution and smoke density is also located within the furnace stack (item 6, Fig. 7). For temperature measurement, two thermocouple junctions are embedded in a ½-in.-diameter copper rod, 17 in. long, held horizontally within the stack. The smoke density is measured by a photoelectric type of smoke meter, which indicates the reduction in intensity of a column of light passing horizontally through the stack to a photocell.

2. Comparison Standards

A red oak standard, to which an index value of 100 is arbitrarily assigned for flame spread, fuel contribution, and smoke density, consists of plain-sawn select-grade red oak flooring, chosen to be within the density range of 37-41 lb/ft³. This flooring is nailed to a backing of ¼-in.-thick plywood.

An asbestos millboard standard ¼-in. thick is used with the arbitrarily assigned index value of 0 for flame spread, fuel contribution, and smoke density.

3. Procedure

The temperature at the center of the top surface of the partitioning plate is first adjusted to be at 85°F ± 5. The test panel is then placed face down within the angle-iron frame (items 4 and 5, Fig. 8) and the cover (item 10, Fig. 8) placed over the back. The lower burner (item 1, Fig. 8) and ignition burner (item 3, Fig. 8) are then lighted.

The gas is burned in the main burner at a rate of approximately 3400 Btu/min with a supply of primary air adequate to produce a blue flame. The exact regulation of this supply of gas depends on the particular characteristics of the individual furnaces and the emissivity characteristics of the partitioning plate. This gas supply should be regulated so that flames travel the length (87 in.) of a standard red oak specimen within the furnace in 18-20 min. This heating rate is then standardized for all subsequent tests until the next recalibration with a red oak standard specimen. Corrections in the volume of gas used to maintain this heating rate may be necessary from run to run, using conventional gas laws, depending on the changes in temperature, pressure, and heat content of the gas.

Following the ignition of the two gas burners, the progress of the flame is observed on the underside of the specimen through the observation ports (item 4, Fig. 7). As the flame front passes each port, the operator notes the time and distance traveled. Temperatures and smoke-density values for the combustion products in the stack are recorded every 30 sec.
4. Calculations

a. Flame Spread

The time to travel the 87 in. of exposure of the standard red oak specimen is between 18 and 20 min. If the time for the flames to spread the length of the test specimen is less than for red oak, the calculation of the flame-spread index is

\[
\frac{\text{time to reach end of red oak specimen}}{\text{time to reach end of test specimen}} \times 100
\]

When the time for the flames to spread the length of the specimen is greater than for red oak, the calculation of the flame-spread index is

\[
\frac{\text{distance reached on test specimen during standard test period}}{\text{distance reached on red oak specimen (87 in.) during standard test period}} \times 100
\]

b. Fuel Contribution

The fuel-contribution index is obtained by planimetering or weighing the time-temperature curve areas for the test specimen and the red oak and asbestos standard specimens. The fuel-contribution index is then

\[
\frac{(\text{area under specimen curve}) - (\text{area under asbestos curve})}{(\text{area under red oak curve}) - (\text{area under asbestos curve})} \times 100
\]

C. Smoke Density

The smoke-density index value is obtained by planimetering or weighing the light obscuration-time curve areas for the test specimen and the red oak and asbestos standard specimens. The smoke-density index is then

\[
\frac{(\text{area under specimen curve}) - (\text{area under asbestos curve})}{(\text{area under red oak curve}) - (\text{area under asbestos curve})} \times 100
\]

D. Factory Mutual Construction Materials Calorimeter Method

This test method (49,65) was devised by the Factory Mutual Engineering Division for classifying construction materials with respect to potential contribution to property fire damage when the fire originates in a local exposure. The equipment provides a quantitative measure of the heat release rate of a material or assembly when subjected to a standard fire exposure. It does not measure flame spread. The developers of the equipment believe the heat release rates present a clearer picture of the manner of burning during the test period than those methods using observed flame spread.
The only one of these calorimetric furnaces currently in use is at the Factory Mutual Engineering Division, Norwood, Mass., where it is used for the development and approval of fire-retardant products, particularly those involved in roof-deck assemblies.

1. Apparatus and Specimen

The furnace is an insulated combustion chamber, 4 ft wide by 4 ft high by 17½ ft long (Figs. 10 and 11). There are three main heptane burners located at one end of the chamber, with appropriate air inlet openings. At the top of the chamber is a 4-ft² opening where the 4½- by 5-ft specimen, suitably mounted in an angle-iron frame, can be horizontally exposed. Three propane evaluation burners are located adjacent to the specimen opening. Baffles and a flue outlet are located at the opposite end of the chamber. A set of 12 thermocouples is located in the flue stack for measuring the average temperature of the exhaust gases.

2. Procedure

The test specimen, 4½ by 5 ft, enclosed in an angle-iron frame, is placed in position to form the horizontal cover of the furnace. The main burners are ignited, firing at a preestablished burning rate and with proper primary and secondary combustion air preheated to 100°F. An exposure firing rate of 26,500 Btu/min and a test duration of 30 min are used for roof-deck assemblies such as insulated metal and impregnated lumber. For comparing the combustibility of interior finish material, the exposure rate is 17,800 Btu/min and the test duration is 10 min. A record is made of the average flue gas temperature-time data resulting from the heat of the exposure burners and the combustion of the test sample. The test is contained until there is no further heat contribution from the test specimen.
After the furnace has cooled to the same equilibrium conditions as in the original test, a second test, designated the evaluation test, is performed substituting a noncombustible sample for the original specimen. The main burners are used to supply heat at the same rate as in the original test and a metered amount of propane is also supplied to the evaluation burners. The amount of fuel supplied to these evaluation burners is controlled so that the flue gas temperatures obtained with the noncombustible sample are equivalent to those obtained with the original sample; thus the metered amount of fuel supplied to the evaluation burners in the second test has the heat equivalent to that developed by the burning of the specimen in the first test.

From the fuel consumption data for the evaluation burners, it is possible to obtain curves showing rate of heat release and accumulated heat release versus time for the constructions. These data may be used to compare materials or to predict performance in larger buildings by correlation with test fires conducted in a 20-ft-wide by 100-ft-long fire-test building.
E. FIRE-TUBE METHOD
(ASTM STANDARD METHOD E69-50, REAPPROVED 1969)

The fire-tube test method was devised by the U.S. Forest Products Laboratory in the year 1928, and used extensively in the evaluation of the chemicals for the fire-retardant treatment of wood (2,18,19,50). This method became tentative ASTM Standard E69 in 1947 and a full standard in 1950 (14). In addition to its use in research, this method has been used in government specifications and local building codes. Its current use, in addition to research and development studies, is primarily for quality-control purposes to ensure that consistent treatment is obtained from batch to batch.

1. Apparatus and Specimen

The specimen for the fire-tube test is in stick form, ⅛ by ⅜ in. in cross-section and 40 in. long, with a small screw hook inserted at one end so that it may be vertically suspended. The specimen should be cut so as to fairly represent the product under investigation. Shorter pieces may be stapled together to obtain the required length.

The fire tube consists of a 38-in.-long, 3-in.-diameter, 28-gage galvanized iron tube, plus a lower 11½-in.-long chamber for enclosing the ignition burner, as shown in part 1 of Fig. 12. This fire tube with enclosed specimen is then placed on one end of a balance arm (part 2 of Fig. 12), which is assembled over a balance support and weight chart (part 3 of Fig. 12 and Fig. 13). The counterbalancing weights on the balance arm, pointer, and chart are so adjusted that the percentage weight loss of the test specimen can be read at any time during the test. The burner is a low-form (curved stem) Bunsen type with a ⅜-in. ID. A thermocouple junction is used at the upper end of the tube, just above the specimen, to indicate temperature.

2. Procedure

The burner is adjusted to produce a blue flame approximately 11 in. high. Placed within the empty fire tube, its top even with the upper edge of screened section, the burner should be adjusted further to produce a constant temperature of 180°C ± 5 at the top of the tube. A manometer should be used in the gas supply line so that the amount of gas to the burner can be constantly controlled during tests.

The fire-tube counterbalancing weights and weight scale should be adjusted so that the pointer shows 100% on the scale when the warmed fire tube is empty, and 0% when the specimen is in place.

The preconditioned specimen, usually at a moisture content of 7 ± 3%, is placed within the fire tube and suspended by the hook at the end. The
lighted Bunsen burner is then placed within the fire tube with the burner top centered and 1 in. below the lower end of the suspended specimen. The flame is applied to the test specimen for 4 min, then withdrawn.

3. Observations

At ½-min intervals throughout the test, the temperature at the top of the tube and the percentage weight loss are observed, until no further weight loss is indicated. A record may also be made of the times for ignition, flaming to various heights within the tube, and cessation of flaming and glowing.

Significant values often used for comparative purposes are the weight loss at 3 min and the final weight loss. For untreated southern pine (0.52 sp. gr.) conditioned at 80°F and 30% relative humidity, the weight loss at 3 min is approximately 65% and final weight loss is 84%. Moderately effective fire-retardant treatments reduce the weight loss at 3 min to 30%, and the most
Fig. 13. Assembly of fire-tube apparatus (Courtesy American Society for Testing and Materials).
effective treatments can reduce the final weight loss to 25% or less. Maximum temperatures at the top of the tube are usually reduced from 700 to 300°C or less for the effective fire-retardant treatments.

F. CRIB METHOD
(ASTM STANDARD METHOD E160-50, REAPPROVED 1969)

Various types of crib-form tests have long been used for measuring the burning characteristics of treated wood. Boundin and Donny of the University of Ghent are reported (33) to have used cribs consisting of 4-36 sticks in fire-performance tests conducted in 1887. The New York Department of Building specifications, developed in 1912, specified a 10-stick crib test, and current New York City building laws specify a 12-stick, 6-in.² crib made of three tiers of ½- by ½- by 6-in. pieces.

A 24-piece crib test was developed at Columbia University and adopted as a tentative standard by ASTM in 1941, and was issued as a full ASTM standard in 1950 (16). The original version of this method (2,19) includes a feature for continuously weighing the specimen during tests.

The use of this method has been limited so far to the development of fire-retardant-treated wood and to quality control of treated wood by producers and by the Underwriters’ Laboratories, Inc.

1. Apparatus and Specimen

The specimen for this test consists of 24 pieces of test material, ½ by ½ by 3 in. in size, arranged in crib form within a wire frame, as shown in Fig. 14. The crib is formed of 12 alternate tiers of two pieces each, with the outer edges of the pieces in each row being 2 in. apart. A 2-in.-diameter Meker-type burner is used for this test in combination with a 6-in.-ID ring stand. The wire frame is designed to fit over the ring stand so that the distance from the top of the Meker burner to the bottom tier is 1½ in. A flame shield, located above the crib in Fig. 14, is used in the initial calibration of the burner, and may also be used over the crib specimen during the test, if there are likely to be any noticeable drafts.

2. Procedure

The test pieces, previously conditioned to a moisture content of 7 ± 3 %, are weighed and then placed in 12 tiers of two pieces, each within the wire frame (Fig. 14). The pieces in each tier are placed at right angles to those in the tier below, with the outer edges 2 in. apart.

The Meker burner is adjusted with the flame shield in place to produce a blue flame 10 ± ½ in. high, with the individual jets about ½ in. high, directly over the grid, without forming a common inner cone or causing the grid to
glow. The gas flow should be adjusted so that the temperature, as measured by an 18-gage chromel-alumel thermocouple 1/4 in. above the tope of the flame shield, is 600°F ± 15. The burner is then removed, the shield raised, and the frame carrying the crib specimens placed upon the ringstand. The flame shield may be repositioned if noticeable drafts are present.

The igniting flame is inserted under the ring stand, directly below the center of the crib. After 3 min, the igniting flame is removed. The specimen is not disturbed and observations are made of the time (sec) from removal of the burner until (1) flaming ceases and (2) glowing ceases. Observations may be made for the flaming and glowing periods for each of the 24 pieces, and a weighted average reported. By an alternate method, the number of pieces flaming and glowing at 20, 45, and 90 sec after removal of igniting flame are reported.

After all flaming and glowing have ceased and specimen has cooled, the specimen, including any fallen pieces, is weighed. The loss of weight expressed as a percentage of original weight of the specimen is then reported.
G. MODIFIED SCHLYTER-PANEL METHOD

This is a simple, vertical flammability test method originated by Ragnar Schlyter of Sweden, and has been modified by the U.S. Forest Products Laboratory (57). The modified method has been particularly useful in evaluating fire-retardant coatings and has been used by industry in developing fire-retardant panel products (35). The method is extremely useful because of its simplicity and because modifications can be made readily to increase or decrease the severity of the test.

1. Apparatus and Specimen

The specimen required for this test consists of two 12- by 31-in. sections of the panel board product of nominal thickness. The two sections are placed vertically within an angle-iron frame, as shown in Fig. 15, with the test surfaces facing each other and separated by a 2-in. space. The bottom edge of one panel is placed directly on the work table, and the other panel is raised 4 in. A suitable scale for measuring the height of the flames is provided.

Fig. 15. Mild “modified” Schlyter-panel test apparatus.
Two types of burners are used: one is a low-form Bunsen burner equipped with a wing top, and the second is a No. 4 Meker burner equipped with a special T-head, consisting of 1¼-in.-OD brass tubing 5 in. long with two rows of 12 holes each (0.128 in. ID) drilled in the upper portion on ¼-in. centers and at an angle of approximately 45° with the vertical.

2. Procedure

In the mild Schlyter test, the two panels are placed in position with the test surfaces facing each other. The Bunsen burner is adjusted to produce a yellow flame as a gas rate of 100 Btu/min. The burner is quickly inserted at the bottom of the assembly midway between the panel edges, with the gas openings of the wing top at right angles to the faces. The height of the flame on the panels is recorded immediately at the start of the test and at 15-sec intervals thereafter. The burner is usually removed after 3 min of exposure, and the average increase in flame height computed. For more severe tests, the burner can be left in place for a longer period; then by observing the time required for the flame to penetrate through the panel, comparative data can be obtained as to the effectiveness of coatings on the flame-penetration characteristics. Usually a record is also made of the time required for both flaming and glowing to cease after removal of the test burner.

In the severe Schlyter test, the Meker burner with special T-head is adjusted to produce a blue flame (with indistinct yellow tips) when the gas is regulated to a gas rate of 300 Btu/min. The burner is inserted between the panels halfway between the faces and midway between the edges of the panel. The top of the T-head is kept parallel to the panel faces. Records are kept similarly to those for the mild Schlyter-panel test.

II. FEDERAL SPECIFICATION SS-A-118b FIRE TEST FOR ACOUSTICAL TILE UNITS

This test method was adopted by the government in 1939 and used for many years as a means of classifying the fire-hazard characteristics of acoustical tile units (60). The use of this method for the evolution of acoustical tile units by code and commercial groups has largely been replaced by the ASTM E84 large-tunnel furnace method.

1. Apparatus and Specimen

The test specimen is a 36- by 36-in. section of acoustical tile units formed into a flat panel over a backing of ½-in.-thick asbestos millboard. An angle-iron frame (½, by 2 by 2 in.) (Fig. 16) is used to support the test panel in a horizontal position at a distance of 60 in. from the floor level. The opening at
the top of the frame is 30 in. Sheet-metal covering is used on three sides of the frame to reduce any draft conditions. A ¾-in.-diameter gas-air-pressure burner is used to provide the fire exposure for this test and is located with its top 28¾ in. below the surface of the horizontally exposed specimen. An 8-gage chromel-alumel thermocouple, with the end of the leads formed into a 3-in-diameter horizontal loop and with the junction at the center, is located 1 in. below the center of the specimen.

2. Procedure

The test panel is placed horizontally face down on the angle-iron frame, and suitably weighted in place. The flame of the burner is adjusted to be in the center of the test panel, and to follow a prescribed time and temperature relationship. For “noncombustible” and “fire-retardant” materials, the exposure is for 40 min and the gas flames may cover up to 12-in.-diameter areas on this panel. For “slow-burning” and “combustible” materials, the test is for 20 min and the gas flames may cover up to 8-in.-diameter areas on the test panel. Observations are made throughout the test as to the amount of flames emitting from the specimen, areas involved in flaming, whether the flames reach the angle-iron frame, duration of flaming, glowing combustion, and the general integrity of the specimen at the end of the test.
3. Classification

The test material is classified as “noncombustible” if the specimen remains in one piece, no flames issue from the specimen during or after the flame application, and the glow does not progress beyond the fire-exposed areas.

The test material is classified as “fire retardant” if the specimen remains in one piece, flaming is limited to intermittent short flames from the area directly exposed to the gas flame, no flame reaches the angle-iron frame, flaming lasts no more than 2 min after the gas flame is discontinued, and no glow progresses to the edge of the specimen.

The test material is classified as “slow burning” if the specimen remains in one piece, no flames reach the end of the angle-iron frame, all flaming ceases within 5 min after the gas flame is discontinued, and no glow progresses to the edge of the specimen.

The test material is classified as “combustible” if it does not conform to any of the three classifications described.

I. FIBERBOARD INCLINED-PANEL METHOD
(COMMERCIAL STANDARD CS-42)

This method is a mild fire-hazard test included in the Commercial Standard for structural fiber insulating board (55). Various modified forms of inclined-panel tests have also been used by research laboratories for preliminary evaluation. These tests, however, are usually mild because there are no self-radiation or external-radiation sources provided.

1. Apparatus and Specimen

The specimen is a 12- by 12-in. section of the fiberboard or other panel material under investigation. The specimen is supported near the corners by the points of four vertical, 1/8-in.-diameter steel rods (Fig. 17). The rods are securely mounted in a horizontal steel plate, with the points of the front two rods 11 in. above the plate and 7 in. apart, and the points of the back two rods 4 in. above the plate.

Each pair of rods is spaced 11 in. apart and the distance from front to back rods is 7 in., resulting in a 45° inclined position of the panel. A flat steel cup, 3/8-in. ID and 1/4-in. deep, is positioned on a stand so that the center of its base is 1 in. below the underside of the specimen and at a point 3 in. above the lower horizontal edge of the test specimen.

2. Procedure

Absolute ethanol (1 cm³) is pipetted into the cup after being positioned on its stand. Next, the specimen, which has been conditioned to equilibrium at 80°F and 50% relative humidity, is placed in position on the pointed support
rods. The test is then performed in a darkened, draftfree room by igniting the alcohol with a match.

A record is made of the time for the flame to reach the upper horizontal edge. One minute after the alcohol has been exhausted, observations are made of any flame or glow on the specimen and then the flame or glow is extinguished. Next the area of char is measured. These values are reported and form the basis of the fire-hazard classification assigned to the specimen.

J. FOREST PRODUCTS LABORATORY’S ROOM CORNER WALL–CEILING METHOD

To obtain a realistic indication of the rate of flame spread over combustible wall and ceiling surfaces, the U.S. Forest Products Laboratory conducted full-scale corner wall–ceiling tests within a “burnout” room (23). The results
of the smaller-scale laboratory tests then were compared to these results (24,42). Other laboratories, such as Factory Mutual Engineering Division, Underwriters’ Laboratories, Inc., and the University of California recently have also developed and used room corner wall-ceiling tests for the evaluation of plastic foam assemblies.

1. Apparatus and Specimen

The room for the FPL test is 8 by 12 ft with an 8-ft ceiling. The room is constructed of cement block walls, wood floor joists, and ceiling members, wood flooring, and the ceiling covered with ¼-in.-thick asbestos millboard. The room has two wood-framed windows and a wood door, but they are closed during the test and therefore are not considered an integral part of the test. One draft inlet, 8 by 16 in., is located in the floor near the midlength of one of the 12-ft walls. Two outlet ports, 6 by 16 in., are located at the ceiling in the corner diagonally opposite the inlet port, each outlet port is located 5 ft from the corner.

The specimen for this test is constructed of two 4- by 8-ft sections mounted vertically in the corner over 1- by 2-in. wood furring strips, wrapped with asbestos paper. On the ceiling, the same material is used to cover a section at least 4 ft wide for 7 ft along each of the two walls. The ceiling material is nailed directly through the asbestos ceiling panels to the supporting ceiling joists.

The ignition fire is supplied by a wood crib consisting of 20 hard maple sticks, weight 2,245 ± 2 grams when conditioned to a moisture content of 6–7%. These sticks are arranged in the form of an open crib of five tiers with four sticks per tier. The sticks are spaced approximately 2 in. apart, and the tiers are laid alternately at 90° angles from each other. This crib is supported on an angle-iron frame approximately 4 in. above an asbestos sheet laid over the corner section of the flooring. This height is sufficient to permit placement of a 6-in.-diameter steel pan, containing ignition fluid, beneath the crib.

Thermocouple junctions are placed on the ceiling just above the crib and at various distances along the wall and ceiling panels, for measuring temperature.

2. Procedure

After the test specimen is attached to the wall and ceiling and the thermocouple junctions are positioned, the wood crib is placed in the corner ½ in. from each wall surface. Fifty cubic centimeters of 95% ethanol is poured into the cast-iron pan and placed beneath the crib. The alcohol is then ignited and the door and all windows closed so that the venting is limited to the one inlet port and the two outlet ports.
Observations are taken of the time to ignite the walls, height of flame on walls, time to ignite the ceiling, time to reach the wall exhaust ports or maximum distance reached on wall or ceiling surface, and temperature. It requires 5.25 min for the flames to reach the exhaust ports on red oak test surfaces, and the total height of flame with asbestos millboard paneling is 5.5 ft; therefore, a flame-spread index can be computed based on the ratio of the time to reach the exhaust port on red oak compared to the time on the test material, or if the flames do not reach the exhaust port, the ratio of flame distance traveled on the test material in excess of 5.5 ft compared to 7.5 ft (i.e., the distance from a height of 5.5 ft to the exhaust ports).

**K. BRITISH SPREAD-OF-FLAME TEST (BRITISH STANDARD 476, PART 1)**

Of the flame-spread methods used in foreign countries, the British spread-of-flame and fire-propagation tests are the best known. The British Standards Test (22) was established in 1945 and has been used by the British Joint Fire Research Station for classifying the surface flammability characteristics of wall and ceiling materials. Other laboratories, such as the Fire Safety Institute in Delft, the Netherlands, and the Australian Commonwealth Experiment Station, have also used this method.

It has been shown that this test is insufficiently discriminating for materials of low fire hazard; therefore, the foreign countries mentioned have developed alternate test methods to supplement or replace the spread-of-flame test. There has also been some recent revision (22h) of this test, including a preliminary spread-of-flame test in which the specimen is approximately $\frac{1}{3}$ the linear size of the original.

**1. Apparatus and Specimen**

The specimen to be tested consists of a 9- by 36-in. section of the test material of nominal thickness. A millboard frame of wood-asbestos is used to position the specimen in a vertical position with its long axis horizontal and perpendicular to one side of a 3- by 3-ft., gas-fired, radiant panel at its midpoint, as shown in Fig. 18. The frame is constructed so that the face of the specimen may burn without obstruction.

The radiant panel is constructed and regulated so that the temperature of that portion of the specimen nearest the radiant panel is 500°C, and temperatures at successive 3-in. increments measured outward along the length of the specimen will be 435, 385, 345, 310, 280, 250, 225, 200, 180, 160, 145, and 130°C, respectively. The temperatures are measured with a blackened, 1-in.-diameter, 0.0084-in. gold disk, with a 24-gage chromel-alumel thermocouple silver-soldered flush with the face.
2. Procedure

After the radiant panel has been adjusted to produce the specified temperatures, the specimen (properly secured in its frame) is brought from room temperature into place and within 5 sec is exposed to the radiant heat. Immediately on exposure to the radiant heat, a 7-in. flame, emanating from a 8-in.-diameter orifice placed within ¼ in. of the surface of the specimen and ¼ in. above its lower edge, is applied for 1 min at the hot end of the specimen. As soon as the igniting flame is in contact with the specimen, observations are made of the time for the flame front to progress measured distances along the length of the specimen. Measurements are made until the flames become extinguished or for 10 min, whichever is longer.

3. Calculations

To compute the classification of surface spread of flames, data are collected from six specimens and an effective spread of flame computed for (I) distance
of spread during the first 1½ min; (2) distance of spread at 10 min; and (3) the final distance of flame spread. The effective spread of flames for the six specimens for each of these distances is equal to

$$X + 1.04\sqrt{(x_1 - \bar{X})^2 + \cdots + (x_6 - \bar{X})^2}$$

where $\bar{X}$ is the mean value and $x_1, \ldots, x_6$ are the individual values for the six specimens.

The classifications for the surface spread of flame are then as follows:

Class 1. Surfaces of very low flame spread—those faces on which not more than 7½ in. of effective spread of flame occurs.

Class 2. Surfaces of low flame spread—those faces on which effective spread of flame neither exceeds 12 in. during the first 1½ min nor exceeds a final value of 24 in.

Class 3. Surfaces of medium flame spread—those faces on which the effective spread of flame neither exceeds 12 in. during the first 1½ min nor exceeds 33 in. after 10 min.

Class 4. Surfaces of rapid flame spread—those faces on which the effective spread of flame either exceeds 12 in. during the first 1½ min or exceeds 33 in. after 10 min.

L. BRITISH FIRE PROPAGATION TEST

The British Joint Fire Research Station experimented with and developed this test procedure (20) in 1955 for the purpose of increasing the sensitivity within the Class 1 range, as normally measured by the Spread of Flame Test (BS 476). This fire-propagation (building board) test method, sometimes referred to as the “hot box” test, has been fairly successful in dividing materials within the Class 1 range into two groups. It has now been introduced into the official British Standards (22a).

1. Apparatus and Specimen

The specimen used for this test is 9 in.² and of nominal thickness. The specimen is placed vertically forming one side of a small furnace enclosure having inside dimensions of 7½ by 7½ by 3 in. deep (Figs. 19 and 20). The enclosure is constructed of ½-in.-thick asbestos board having a thermal conductivity not exceeding $5.12 \times 10^{-4}$ cgs units. The asbestos board is suitably fastened to an outer reinforcement of 20-gage, mild sheet steel. Air is supplied through a 1-in. horizontal opening at the lower rear of the chamber and exhaust gases are vented through a chimney, 1½ in. in diameter and 7 in. high, located at the top. A 3-in.-diameter by 6-in.-high cowling is located above the chimney. Thermocouple junctions are installed near the
bottom edge of the cowling to measure flue gas temperatures. A 1-in.-diameter pipe burner, with 14 holes ½ in. in diameter, is located at the lower edge of the test specimen and at a distance of ⅛ in. from the face. Two electric, resistance-type heating elements, each of 1000 W maximum capacity, are located in the center of the furnace 2½ in. apart and 2½ in. from the top and bottom of the chamber. A mica window is provided in the furnace wall opposite the test specimen.

2. Procedure

The specimen is positioned at one side of the chamber, so that a 7½- by 7½-in. area is exposed to the heating elements. The specimen is backed with ⅛-in.-thick asbestos board and clamped in place to ensure proper sealing. The burner with 14 gas-jet openings is lighted and adjusted to provide an
exposure rate of 30 Btu/min; then after 3 min, supplementary heat is added from two electrical radiant heaters at a rate of 85 Btu/min (1500 W total). The test is continued for 20 min and a continuous record obtained of flue gas temperature versus time of exposure.

3. Calculations

The time-temperature curve for the specimen is compared to a standard curve, which is obtained by adding 50°C to a calibration curve obtained on a noncombustible sample under the same test conditions. The British Joint
Fire Research Organization originally proposed the following classification:

Class A. Materials for which the flue temperature does not reach the “standard curve” within the first 3 min and exceeds the “standard curve” for less than 3 min.

Class B. Materials for which the flue temperature does not reach the “standard curve” until after 5 min and exceeds the “standard curve” for more than 3 min.

Class C. Materials for which the flue temperature reaches the “standard curve” within 3-5 min and exceeds the “standard curve” for more than 3 min.

Class D. Materials for which the flue temperature exceeds the “standard curve” in 3 min or less.

The British Standard Committee prefers an index system based on the following:

1. The time from the start of the test when the time-temperature curve for the material first crosses the “standard curve.”
2. The time for which the time-temperature curve for the material remains above the “standard curve.”
3. The maximum temperature difference between the time-temperature curve for the material and the “standard curve.”
4. The time at which this maximum occurs and the temperature above atmospheric of the “standard curve” at that time.

III. FLAMMABILITY TEST METHODS FOR PAINT COATINGS

In addition to general flammability methods, many of which can be applied to painted products, some flammability methods have been developed which are primarily limited to use with painted surfaces. These include the cabinet method (10), which has had some recognition in federal specifications for fire-retardant paints (35,61); the stick and wick method (11); and the recently developed 2-ft inclined-panel (tunnel) method (64).

A. INCLINED-PANEL CABINET METHOD
   (ASTM STANDARD 1360-70)

This method has been limited to evaluating paint coatings. Although there has been some use of the method in specifications for fire-retardant paints, its main use has been in research and development.

1. Apparatus and Specimen

The apparatus consists of a sheet metal and glass cabinet as shown in Fig. 21, with the frame for positioning the test panel at an angle of 45°. The fuel cup, which may be positioned at several distances from the test
surface, is of brass, 1/16 in. in height, 5/8 in. OD, and with a wall thickness of 1/32 in. The test panels are of 3/8-in.-thick yellow poplar heartwood, 6 by 12 in. in size, with the grain direction lengthwise in the panel. Surfaces are smooth planed and sanded prior to use. The panels may be either solid or glued together to obtain the necessary width. No individual strips shall be less than 1½ in. wide, and heat-resistant adhesives should be used for the gluing. The panels shall be selected to be within a density range of 27-30 lb/ft³ when conditioned to a moisture content of 8%.

2. Procedure

The test specimens are prepared by first conditioning them for 2 weeks at 50-60% relative humidity at 70-75°F. Paint coatings are then applied.
to all surfaces of the test panel, including edges and ends, by brushing on one coat at 250 ft²/gal or in two coats at 500 ft²/gal. Twenty-four hours of drying should be allowed between coats and 2 weeks of drying after the final coat. Conditioning should be at 50–60% relative humidity and 70–75°F. Prior to test, the panel is given an additional conditioning of 40 hr in an oven at 120°F ± 3.

The test panel is weighed to the nearest 0.1 gram and then placed face down on the angular supports, with the lower edge 2 in. from the angle formed by the floor and the side wall of the cabinet. The fuel cup is placed so that its edge nearest the panel is 1 in. away from the panel when measured vertically.

Five milliliters of absolute ethanol is placed in the cup and ignited without delay, using a small jet flame. The door to the cabinet is then closed, and the test is allowed to continue until all flames are self-extinguished.

3. Calculations

After cooling to room temperature, the test panel is reweighed to the nearest 0.1 gram. To be classified as fire retardant, the average weight loss for five test specimens should be less than 17.0 grams.

Next the test panel is quartered along maximum length and width of charring. The maximum width of charring of the wood is measured in both longitudinal and lateral cuts, and also the average depth of wood charring is determined. A char volume is then computed for the test panel.

B. STICK AND WICK METHOD
(AMST STANDARD D1361-58, REAPPROVED 1970)

1. Apparatus and Specimen

The specimen for this test consists of a white sugar pine stick, 1 by 1 by 16 in. in length. Sticks are selected to be within ± 5% of the average density, and then sets of three are selected to represent high, low, and average density specimens within this group.

The test apparatus consists of a 24-gage sheet-metal fire shield, measuring 8 by 11 by 30 in, high, open at the top, and provided with (1) 12 air inlets, ½ in. in diameter, distributed symmetrically in a horizontal line 1 in. above the base; (2) a sliding glass observation panel; (3) means for mounting and rotating the test specimen in a vertical position; (4) graduated scale for measuring flame height; and (5) carbon dioxide gas extinguisher for quickly extinguishing flames at the end of test.

There is also a 2-in.-diameter nickel crucible for placement in the center of the floor of the fire shield and an ignition wick for supplying the fuel
source. The wick is a 6-in. length of 4½-in.-wide Red Cross gauze, US. Type 111, folded twice lengthwise.

2. Procedure

The apparatus is first calibrated by wrapping a wick around a glass tube or other noncombustible object and snugly placing the assembly in a vertical position within the ignition cup in the center of the shield. The wick is evenly wetted with 4 ml absolute ethanol and ignited. The graduated measuring scale is placed so that its start coincides with the highest point reached by the flame front. This calibration and subsequent tests should be conducted under a laboratory hood under essentially draftfree conditions.

The test specimens are dried for 72 hr in an oven at 140°F prior to paint application. Two coats of the paint are applied to the test surfaces at a rate of 500 sq ft²/gal per coat. The entire stick is coated except the lower 1½-in. portion. The sticks are allowed to air dry for 24 hr between coats, and for at least 14 days after the second coat, Prior to test, the coated sticks are given an additional drying for 72 hr in an oven at 140°F.

In fire testing, unpainted controls or the painted specimens are first weighed to the nearest 0.1 gram. The wick is then wrapped around the lower portion of the stick and thrust with rotary motion into the ignition cup, with the top of the wick even with the top of the cup. Four milliliters of absolute ethanol is uniformly applied to the wick. The assembly is mounted in a vertical position within the fire shield. The wick is ignited and timing started. The flaming stick is rotated one-half turn whenever necessary to equalize the burn pattern on all four sides. The height of the flame is observed, and the highest reading during each 10-sec interval is recorded. The test is continued for 100 sec, and then the flaming quickly extinguished with carbon dioxide. After cooling, the stick is reweighed. The average height of char on each stick is also determined by mild pressure with a knife blade on the corners of the stick.

3. Calculations

The average data for sets of three specimens are compared to the unpainted controls as

\[
W = \frac{\text{average percent weight loss - test sticks}}{\text{average percent weight loss - control sticks}} \times 100
\]

\[
F = \frac{\text{average height of flame spread - test sticks}}{\text{average height of flame spread - control sticks}} \times 100
\]
where the average height is obtained by dividing the 10 height readings taken during the test by 10. If the test flaming reaches a maximum and recedes on the test specimen, the average height of flame spread for the 10 readings is multiplied by the fractional time elapsed when the maximum was reached.

\[
C = \frac{\text{average height of char - test sticks}}{\text{average height of char - control sticks}} x 100
\]

A burn index is then calculated as follows:

\[
\text{burn index} = \frac{W + F + C}{3}
\]

C. TWO-FOOT INCLINED-TUNNEL METHOD

This method has recently been developed (64) for preliminary evaluation of fire-retardant paint systems.

1. Apparatus and Specimen

The apparatus consists of an angle-iron frame (1 by 1 by ¼ in.) to hold a 4- by 24-in. panel specimen, inclined lengthwise at a 28° angle upward from the horizontal. The lower edge of the panel is positioned 7 3/8 in. above a ½-in. steel plate which provides the base for the frame. Asbestos-cement hardboard sheets are provided along both undersides of the frame extending down to the base to result in a “tunnel” through which the rate of draft may be controlled. A Fisher burner is located near the lower end of the underside of the test panel, so that the distance from the top of the burner to the underside of the test panel is 1¾ in.

2. Procedure

The test panel, with paint coating applied and conditioned for a minimum of 2 days at 75°F and 50% relative humidity, is placed face down within the angle-iron frame. This panel is then covered with an asbestos backing plate containing thermocouple junctions and a steel backing plate. The gas burner is adjusted to give a flame height of 6 in. and the burner is placed in the standard position at the lower end of the specimen. Observations are then made of the time for the flames to travel fixed distance over the underside of inclined specimens, and temperature measurements are taken to indicate insulative effects of the coatings. The burner is turned off at the end of 5 min and observations are made of afterflaming, afterglow, and weight loss.
3. Calculations

The maximum flame-spread length during a 4-min recording period is compared to maximum flame-spread length for asbestos and red oak panel standards. The maximum flame-spread length for asbestos is subtracted from the value for the sample, and then the increase in flame spread is compared to the similar increase for uncoated red oak rated at 100. For example, if the increase in maximum flame-spread length is only 50% of that obtained with the red oak specimen, a value of 50 is assigned as the flame-spread rating.

IV. FLAMMABILITY TEST METHODS FOR PLASTICS

In addition to the flammability methods for building materials as applied to plastic products, there are several small-scale, fire-test methods which apply principally to plastic products. Generally these involve a mild ignition source, and the observation of ignition and rate of burning of the plastic specimen in a vertical, horizontal, or inclined position. These small-scale tests are primarily intended for research or development purposes or for nonconstruction purposes, where the fire performance characteristics are not critical.

A. FLAMMABILITY OF FLEXIBLE PLASTICS

(ASTM STANDARD METHOD D568-74) (4)

1. Apparatus and Specimen

The test specimen for this test is a 25-mm by 45-cm section of the test material. Specimens are cut in both machine and transverse directions from the materials. A gage mark is made 38 cm from the one end so that the burning rate can be determined.

The apparatus consists of shield, specimen clamp, burner, and timer. The shield is constructed of sheet metal to provide an inside dimension of 300 by 300 by 760 mm in height. The shield is open at the top, and has a 25-mm-high ventilation opening around the sides of the bottom. The shield also has a viewing window constructed of heat-resistant glass.

2. Procedure

The specimen is clamped vertically in the center of the shield with 43 cm exposed below the clamp. The shield is located within a hood, but all direct drafts are minimized. A Bunsen burner flame approximately 25 mm high is applied to the lower end of the specimen for periods up to 15 sec to obtain
ignition. The timer is started as soon as flaming reaches the lower gage mark and stopped when the flaming reaches the upper mark. The burning rate is reported of all specimens that burn to the upper mark.

**B. FLAMMABILITY OF SELF-SUPPORTING PLASTICS**

**(ASTM STANDARD METHOD D635-74) (6)**

1. **Apparatus and Specimen**

The specimen for this test is a 125- by 12.5-mm section of the plastic in the thicknesses normally supplied. A scribe mark is located 100 mm from the end of the specimen so that burning rate can be observed over this length. The test is conducted within a suitable hood with viewing window enclosed with heat-resistant glass.

2. **Procedure**

The test specimen is clamped horizontally at the one end of the 125-mm length. The edge of the plastic piece is inclined upward at 45° from the horizontal. A wire gauze is located at a distance of 10 mm below the test specimen to collect any drippings, but positioned so as not to interfere with ignition of the end of test specimen opposite the clamped end. A Bunsen burner flame, which has been adjusted to produce a blue flame 25 mm long, is placed so that the end of flame contacts the exposed end of the specimen. At the end of 30 sec the burner flame is removed and ignition noted. If the plastic does not ignite in the first burner application, the flame is reapplied for another 30 sec. If the plastic continues to burn after the first or second burner application, a record of the time for flames to reach the gage mark is recorded. Reporting is of the “burning rate in centimeters per minute.”

**C. RATE OF BURNING OF CELLULAR PLASTICS USING A SUPPORTED SPECIMEN**

**(ASTM STANDARD METHOD D1692-74) (13)**

This test method provides a laboratory procedure for comparing the relative flammability of plastic foams. Materials that shrink or curl appreciably under test should not be evaluated by this method.

1. **Apparatus and Specimen**

The specimen required for this test is a 50- by 150-mm piece of plastic sheeting or foam in the thickness usually supplied. If more than 13 mm thick, the specimen is prepared as a 13-mm-thick section from the plastic foam. A suitable scribe mark is made on the face of the test specimen, 25 mm from the far end, to aid in determining burning rate characteristics.
The foam or sheet sample is supported flat in a horizontal position on a 75- by 215-mm piece of 6.5-mm mesh, 0.8-mm wire hardware cloth. This hardware cloth is supported at the center of one end by a clamp and a ring stand. At the other end, 13 mm of the hardware cloth is turned up at 90°, and the side of the turned-up cloth is clamped and supported by a second ring stand.

A standard 9.5-mm-diameter barrel Bunsen burner, fitted with a 48-mm maximum-width wing top, is required for the fire exposure. A suitable enclosure must also be provided to ensure draft-free air around the specimen, and yet permit normal thermal circulation past the specimen during burning.

2. Procedure

The hardware cloth is adjusted horizontally between the two supports and ring stands to be 13 mm above the top of the Bunsen burner wing top. The specimen is then placed on the wire cloth with one end of the specimen touching the 13-mm bent-up portion of the hardware cloth. The Bunsen burner with wing top is then adjusted to have a blue flame, with visible portion 38 mm high. The burner is then centered with the flame parallel to the bent-up edge of the specimen support, and extending into the front edge of the specimen.

At the end of 1 min the burner is removed. If there is no evidence of ignition by flaming or progressive glow, the result is recorded. If the specimen continues to burn after the removal of the flame, the time for the flame front to progress to the second gage mark, a distance of 125 mm, is noted. The burning rate is then recorded in millimeters per second. If the specimen shows evidence of ignition, but does not burn to the gage mark, burning and distance burned are recorded.

D. FLAMMABILITY OF FLEXIBLE THIN PLASTIC SHEETING

(ASTM STANDARD METHOD D1433-74) (12)

In brief, this method uses a 76- by 228-mm length of thin plastic sheeting suitably mounted in a specimen holder with 38 mm of width and the lower 178 mm exposed. The bottom 25 mm of the specimen holder is bent down at 45° from the remainder of the holder. The specimen and holder are placed in a special cabinet with the major portion of the specimen inclined upward at 45° from the horizontal and the lower 25-mm portion in the vertical position. A small gas flame (13 mm in horizontal length) emitting from a No. 22 hypodermic needle is then applied in the center of the 25-mm section of plastic film located in the vertical position. The time required for the flames to move along the 45° surface (152 mm) of the specimen is used in computing burning rate in millimeters per second.
E. INCANDESCENCE RESISTANCE OF RIGID PLASTICS  
(ASTM STANDARD METHOD D757-74) (7)

Briefly, this method consists of placing a 13-by 120-mm length of 1.3-mm-thick plastic, with its length in the horizontal plane and its width in the vertical plane, against an electrical-resistance heating bar supported in a horizontal position and maintained at a temperature of 950°C (1742°F). The front edge of the plastic is maintained in continuous contact with the center of the heating rod for 3 min. The burning time, distance burned, and rate of burning are recorded.

V. FLAMMABILITY TESTS FOR FABRICS

Numerous types of tests are available for measuring the burning rates and flame resistance of fabrics, involving vertical, horizontal, and inclined exposure of the test specimens. A few of the more representative tests are described briefly.

A. FABRIC VERTICAL-FLAME TEST

This small-scale test was developed by the National Bureau of Standards (54) and, with minor variations, is described in NFPA Standard No. 701 (41), Underwriters’ Laboratories Standard UL-214 (52), Methods 5902 and 5903 of Federal Specification CC-T-191b (59), ASTM Standard Method D626-55T (5), and in the American Association of Textile Chemists and Colorists Method 34-1952. This type of test is prescribed in Federal Specification CC-C-428C (63).

1. Apparatus and Specimen

The specimen required for this method is a sample of the fabric 2½ in. wide by 12 in. long. The apparatus consists of a Bunsen or Tirrill burner (¼-in. ID), suitably protected from drafts by a box-type sheet-metal shield 14 in. wide by 12 in. deep by 30 in. high. The box shield is provided with ventilation holes at the top and bottom, and also with a front door having a glass insert for use in observing the burning specimen. A metal bar is secured to the base of the burner and extends through a slot at the side of the shield to facilitate positioning of the burner under the specimen when required. A suitable clamp is provided for suspending the specimen vertically, with the clamp covering the upper ½ in. of the 12-in. length and along both vertical edges, leaving an exposed width of 2 in.

2. Procedure

The conditioned specimen is placed in the clamp (within the shield) with the 12-in. length in the vertical position. The Bunsen or Tirrill burner is then
ignited and adjusted with the air supply completely shut off to obtain a luminous flame 1½ in. long. With the door of the shield closed, the burner is positioned so that the flame is applied at the center of the lower end of the specimen for 12 sec and then removed. Observations are made of the period of continued flaming and the average char length obtained for 10 specimens. Char length is defined as the distance between the end of the specimen (that was exposed to the fire) and the end of a tear made lengthwise through the center of the charred area, using the following technique.

Hooks are inserted in the specimen, one at each side of the charred area ÷ in. from the adjacent outer edge. A weight, equal to approximately 10% of that required to tear the unburned cloth, is then attached to one hook, and a tearing force is applied gently to the specimen by grasping the other hook and gently raising the specimen. The specimen tears lengthwise through the charred length until it can support the weight.

A criterion often used for determining a satisfactory performance of flame-retardant material is that no specimen shall continue flaming for more than 2 sec after the ignition flame is removed, and the average char length of the 10 specimens shall not be more than 3½ in.; also, the maximum length of any one of the 10 specimens shall not be more than 4½ in.

**B. LARGE-SCALE VERTICAL-FIRE TEST**

The Underwriters’ Laboratories use a large-scale flame test (52) in evaluating flame-resistant fabrics, in addition to the small vertical test procedure.

1. **Apparatus and Specimen**

Two types of specimen are prepared from each fabric tested. These are single-sheet specimens which are 5 in. wide and approximately 84 in. long, and folded specimens which are 25 in. wide and 84 in. long, folded four times to form an accordion-pleated specimen, 5 in. wide.

The test apparatus is a sheet-steel stack, 12 by 12 in. by 7 ft high, supported 1 ft above the floor on legs. A wire-glass observation window extends the full length of the stack. A Bunsen burner having a ½-in. ID is used for application of flames.

2. **Procedure**

The single-sheet specimen, after being dried for 1–1½ hr at 140-145°F, is suspended vertically within the stack, with its full widths facing the observation window. The bottom of the specimen is 4 in. above the top of the Bunsen burner, when the burner is placed on the floor beneath the stack. The specimen is lightly restrained laterally with clamps and wires attached to the outer edges. A folded specimen is suspended in a similar manner, with the edges of
the folds facing the observation window and the folds spread apart about ½ in.
by guide rods inserted at the top and bottom ends.

The burner, using gas with a heat value of 800-1000 Btu/ft³ and at a pressure
of about 4 in. of water, is adjusted to produce an 11-in. oxidizing flame with
an indistinct inner cone. The flame is then applied vertically near the middle
of the lower end of the specimen for 2 min and withdrawn. The end of the
burner is 4 in. below the bottom of the specimen during this exposure.

Observations are made during and after flame application as to the
duration and length of surface flaming. The length of char is also determined
after the test in the same manner as for the small-scale fabric vertical-flame
test.

C. HORIZONTAL BURNING RATE OF CLOTH

This method is described in the National Bureau of Standards Circular
C455(54) and in the Federal Specification CCC-T-191b (59), Method 5906.

1. Apparatus and Specimen

The specimen is a section of cloth 4½ by 12½ in. with the long dimension
parallel to the warp direction. The specimen is held within a holder consisting
of two matching rectangular frames, each 15½ in. long and 4 in. wide, with
alignment pins. The frames are 1 in. wide by ½ in. thick and are of a corrosion-
resistant metal. Two reference-marking wires are attached to the upper
frame of the holder. One wire is 2 in. from the inside of one end of the frame
and the other wire is 1½ in. from the other end; thus the distance between
wires is 10 in.

The apparatus is a metal cabinet 8 in. wide, 15 in. long, and 14 in. high,
with a glass observation window along one side. The cabinet is fitted with a
top cover having two glass observation windows, one near each end of the
cabinet. The cover is raised to provide a ventilating clearance of ½ in. The
cabinet has support legs at each of the bottom corners so that it can be
raised ¼ in. above a supporting surface. The bottom of the cabinet has five
equally spaced ¾-in.-diameter ventilating holes along each side.

Two electrical resistance-type strip heaters are located in the bottom of the
cabinet just above the ventilating holes, and an immersion thermometer
is inserted in the cover for registering temperature of the cabinet. A ¾-in. ID
Tirrill or Bunsen burner is located at the center of the one end of the cabinet.

A supporting track is provided within the test chamber so that the specimen
holder and specimen can be inserted through a slot in the one end of the
cabinet and be located in a horizontal position, with the center of the one
end of the specimen ¾ in. above the gas burner.
2. Procedure

After conditioning for 4 hr in an oven at 140-145°F, the cloth specimen is slipped into the holder and firmly clamped along each long edge, with \( \frac{1}{2} \) in. between each end of the specimen and the frame of the holder.

With the burner flame low, the specimen holder containing the specimen is slipped through the slot in the end of the cabinet and conditioned for 2 min within the cabinet. The specimen holder is then drawn back to clear the burner, and the burner flame is adjusted to give a 1½-in. flame with the primary air completely shut off. The specimen holder is then again horizontally positioned within the cabinet, with the one end \( \frac{3}{4} \) in. above the top of the gas burner. The temperature within the test chamber is maintained at approximately 140°F during the test.

When 1½ in. of the cloth has burned to the first reference mark, timing is started. The time is then recorded for the flame to progress to the second reference mark (10 in.), and the average rate of burning in inches per minute computed. In napped or double-napped cloth, special techniques are used to reduce flashing.

D. BURNING-RATE TEST OF CLOTH—45° ANGLE

This method and variations are prescribed in many standards, including the Commercial Standard CS191-53 for the flammability of clothing textiles (56), Federal Specification CC-T-191b(59), and ASTM Standard D1230-61(9).

1. Apparatus and Specimen

The specimen is a 2- by 6-in. section of the cloth, cut so that the long dimension is in the direction likely to have the more rapid burning rate.

The test apparatus consists of a draft-proof cabinet, a specimen holder and rack for inclining the specimen at 45° from the horizontal, a butane micro-burner for specimen ignition, and other suitable control and recording devices.

The cabinet is 14½ in. wide, 8½ in. deep, and 14 in. high. There are 12½-in. holes, equidistant along the rear of the top enclosure. Along one of the long sides of the cabinet a sliding glass door is provided with a ventilating strip at the bottom.

The specimen holder consists of two \( \frac{1}{16} \)-in. metal plates which fasten on both sides of the test specimen, exposing a 1½-in. width of the specimen for its full length.

The specimen rack provides support within the cabinet for the specimen holder and specimen, which are at an angle of 45° from the horizontal. Guide pins and knobs project down through the bottom of the cabinet so
that the position of specimen rack can be adjusted to make allowances for the thickness of the specimen in relation to the burner.

The ignition source for the test is provided by a microburner of a 26-gage hypodermic needle burning butane gas which is supplied from a 2-lb-capacity cylinder, equipped with fuel-control valve and flowmeter. The position of the burner should be such that its nozzle is \(\frac{3}{16}\) in. away from the exposed surface specimens. In the commercial version of this equipment, automatic compensation is provided to maintain this distance when testing fabrics of various thicknesses.

A stop cord of No. 50 mercerized cotton is attached to the center of the upper part of the specimen holder (just above the exposed length of fabric) and extends in almost a horizontal position over the exposed length of fabric to a metal support on the opposite side of the cabinet.

2. Procedure

The position of the rack in the cabinet is adjusted with a trial specimen in the holder so that the orifice of the burner is \(\frac{3}{16}\) in. away from the exposed surface. The gas is allowed to flow and burn for at least 5 min, adjusting the burner flame to a \(\frac{3}{8}\)-in. length.

The specimen, which has undergone the prescribed washing, brushing, and drying, is then mounted within the holder and placed within the rack of the cabinet. The stop cord is then strung in the upper plate of the specimen holder and across the upper part of the specimen and to the guides in the rear and end of the cabinet. The door of the cabinet is then closed and a starting lever released, which starts a timing mechanism and applies the flame to the specimen for 1 sec. The timing is stopped when the flame reaches the upper edge of the specimen and the stop cord is burned through. In addition to the time for burning, the ignition time is noted for the base fibers or fusing of textiles having raised fiber surfaces.

VI. FLAMMABILITY TEST FOR PAPER AND PAPERBOARD

In addition to the flame-spread methods prescribed for building materials and plastics, paper and paperboard of less than \(\frac{1}{16}\) in. thick can be evaluated for flammability using ASTM Method D777-46 (8). This method is also TAPPI Standard Method T461os-68.

A. APPARATUS AND SPECIMEN

The test specimen is a section of paper 2¾ in. wide and 8¼ in. long. Specimens are cut in both principal directions of the sheet.
A metal frame is used to hold the specimen by gripping \( \frac{1}{4} \) in. of each long edge, thus exposing an area 2 by \( 8\frac{1}{4} \) in. A \( \frac{3}{8} \)-in ID Tirrill or Bunsen burner is used to apply the fire exposure.

**B. PROCEDURE**

The test specimen is clamped in the metal frame and the specimen and frame positioned with the long axis in a vertical plane. The test flame is adjusted to a height of 1½ in., with the primary air supply closed and in a draftfree location. The test flame is then applied to the center of the lower edge of the specimen at a level where the distance from the top of the burner tube to the edge of the specimen is \( \frac{3}{4} \) in. The flame is applied for 12 sec and then withdrawn. The duration of the afterglow in seconds is noted, and the average height of the charred area is measured.

**REFERENCES**