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NFPA 258
Smoke Generation of Solid Materials
1989 Edition

NFPA

National Fire Protection Association Batterymarch Park, Quincy, MA 02269

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The Board of Directors reaffirms that the National Fire Protection Association recognizes that the toxicity of the products of combustion is an important factor in the loss of life from fire. NFPA has dealt with that subject in its technical committee documents for many years.

There is a concern that the growing use of synthetic materials may produce more or additional toxic products of combustion in a fire environment. The Board has, therefore, asked all NFPA technical committees to review the documents for which they are responsible to be sure that the documents respond to this current concern. To assist the committees in meeting this request, the Board has appointed an advisory committee to provide specific guidance to the technical committees on questions relating to assessing the hazards of the products of combustion.

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NATIONAL FIRE PROTECTION ASSOCIATION

NFPA 258

Standard Research Test Method for Determining Smoke Generation of Solid Materials

1989 Edition

This edition of NFPA 258, *Standard Research Test Method for Determining Smoke Generation of Solid Materials*, was prepared by the Technical Committee on Fire Tests and acted on by the National Fire Protection Association, Inc. at its Annual Meeting held May 15-18, 1989 in Washington, D.C. It was issued by the Standards Council on July 14, 1989, with an effective date of August 7, 1989, and supersedes all previous editions.

The 1989 edition of this document has been approved by the American National Standards Institute.

Changes other than editorial are indicated by a vertical rule in the margin of the pages on which they appear. These lines are included as an aid to the user in identifying changes from the previous edition.

Origin and Development of NFPA 258

The smoke problem that develops during unwanted fires has been recognized for years. There is continuing recognition of the importance of combustion products in playing a major role in the majority of fire fatalities. Fire fighters are faced with the smoke problem daily in their work.

The many ways in which fire gases influence the hazard to life have, so far, precluded an exact technical assessment of them. A test method, such as the one discussed in this standard, has obvious merit as a measurement tool for assisting in research, development, and production quality control of materials and products. Use of the test method for rough analysis of the smoke production during an actual fire is informative in showing the magnitude of the smoke problem.

The smoke density chamber provides a means for characterizing smoke production with an accuracy far in excess of any application requirements which should be recommended. It also provides a means for reporting rate of smoke production and time at which specific smoke levels are reached under the test conditions applied.

The concept of specific optical density, while old in terms of photometric practice, was first introduced for measuring smoke as part of the smoke density chamber test method. It is based on Bouguer's law and permits reporting smoke developed in terms that recognize the area of the specimen involved, the volume of the box, and the optical path length of the photometer. The test method was developed at the National Bureau of Standards and first described publicly in 1967. Since then there have been numerous publications reporting on its application and on studies of the correlation of results of interlaboratory tests through its use.

This standard was first adopted by the NFPA as a tentative standard in 1974. A revised edition was adopted as a standard in 1976, and reconfirmed at the NFPA 1981 and 1986 Fall Meetings. This 1989 edition reflects a minor revision to the scope statements of the standard.

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Contents

NFPA 258

Standard Research Test Method for Determining

Smoke Generation of Solid Materials

1989 Edition

Chapter 1 General

1-1 Scope.

1-1.1 This method of test provides a procedure for measuring the total smoke generated in a closed chamber from solid materials and assemblies in thicknesses up to and including 1 in. (25.4 mm) when subjected to specific test conditions.

1-1.2 Measurement is made of the attenuation of a light beam by the suspended solid or liquid particles (smoke) accumulated within a closed chamber. The smoke is due to either nonflaming pyrolytic decomposition or flaming combustion of a relatively small sample of material.

1-1.3 Results of the test are expressed in terms of specific optical density, which is a dimensionless number derived from the measured light transmission and geometric measurements of the chamber and the specimen.

NOTE: A commentary describing the significance of specific optical density and appropriate considerations for application of test results is included in Appendix C.

1-1.4 This test is intended for use only as a research and development tool. It shall not be used as a basis for determining ratings for building code or other regulatory purposes.

1-1.5 This standard is intended to measure and describe the properties of materials, products, or assemblies in response to heat and flame under controlled laboratory conditions and is not intended to describe or appraise the fire hazard or fire risk of materials, products, or assemblies under actual fire conditions.

1-2 Significance.

1-2.1 This method provides a means for comparing the specific optical density of the smoke generated by materials and assemblies in the form and thickness tested, and under the specified exposure conditions.

NOTE: Attempts are now under way to relate the results of this test to the measurement of smoke generated under large-scale test conditions. Other test methods for measuring smoke have been reviewed and summarized in "The Control of Smoke in Building Fires — A State-of-the-Art Review," *Materials Research and Standards*, 42 (April 1971) pp. 16-23.

1-2.2 Values determined by this test are specific to the specimen or assembly material in the form and thickness tested and shall not be considered inherent, fundamental properties of a given material.

1-2.3 The values stated in U.S. customary units shall be regarded as the standard. The metric equivalent of U.S. customary units given in the standard may be approximate.

1-2.4 No basis is provided for predicting the density of smoke that may be generated by materials upon exposure to heat and flame under other fire conditions or in other atmospheres.

1-2.5 Values determined by this test are specific to the effect of attenuation of light transmission within the chamber of the smoke generated by the material in the form, thickness, and quantity tested when subjected to the energy sources specified. These values by themselves do not provide a basis of predicting material performance in actual fires.

1-3 Summary of Method.

1-3.1 This method for measuring the smoke generated by materials employs an electrically heated radiant energy source mounted within an insulated ceramic tube and positioned so as to produce an irradiance level of 2.2 Btu/sec ft^2 (2.5 W/cm^2) averaged over the central 1½ in. (38.1 mm) diameter area of a vertically mounted specimen facing the radiant heater. The nominal 3 in. by 3 in. (76.2 mm by 76.2 mm) specimen is mounted within a holder which exposes an area measuring 2$\frac{9}{16}$ in. by 2$\frac{9}{16}$ in. (65.1 mm by 65.1 mm). The holder can accommodate specimens up to 1 in. (25.4 mm) thick. This exposure provides the nonflaming condition of the test.

1-3.2 For the flaming condition, a six-tube burner is used to apply a row of equidistant premixed (air-propane) flamelets across the lower edge of the exposed specimen area and into the specimen holder trough. This application of flame, in addition to the specified irradiance level from the heating element, constitutes the flaming combustion exposure.

1-3.3 The test specimens are exposed to the flaming and nonflaming conditions within a closed 18 ft^3 (0.51 m^3) chamber. A photometric system with a 36-in. (914-mm) vertical light path measures the continuous decrease in light transmission as smoke accumulates. Exposure is continued either for 20 minutes or until minimum light transmission is reached, whichever occurs first.

1-3.4 Calibration procedures for the test equipment, such as those described in A-2, shall be followed.

1-3.5 The light transmittance measurements are used to express the smoke generated by the test materials in terms of the specific optical density during the time period to reach the maximum value.

NOTE: Additional parameters, such as the maximum rate of smoke accumulation, the time to a fixed optical density level, or a smoke obscuration index, may be more appropriate in particular situations.

Chapter 2 Test Apparatus

2-1 Test Apparatus. The apparatus shall be essentially as shown in Figures 2-1(a) and 2-1(b). The apparatus shall include that given in Sections 2-2 through 2-11.

NOTE: A more detailed description of the suggested apparatus is given in A-1.

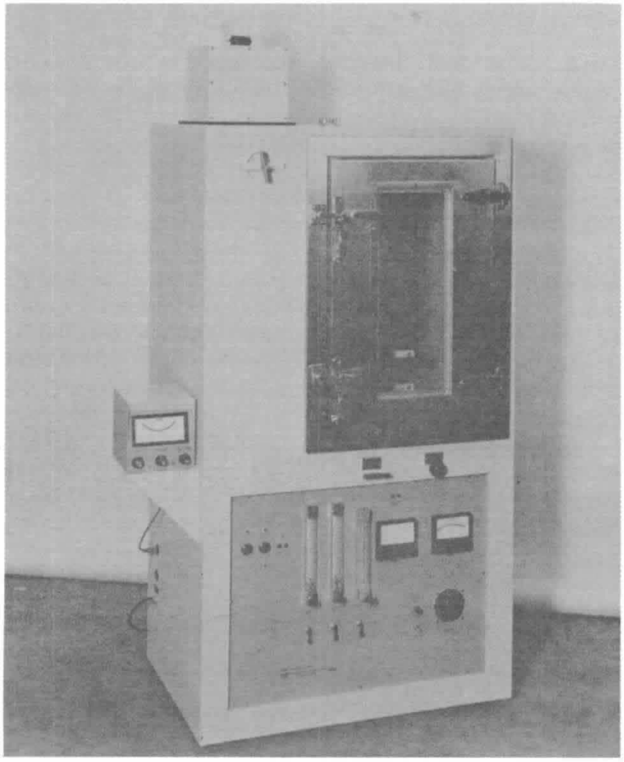


Figure 2-1(a).

2-2 Test Chamber.

2-2.1 As shown in Figure 2-1(b), the test chamber shall be fabricated from laminated panels to provide inside dimensions of 36 in. by 24 in. by 36 in. ± $\frac{1}{8}$ in. (914 mm by 610 mm by 914 mm ± 3 mm) for width, depth, and height, respectively.

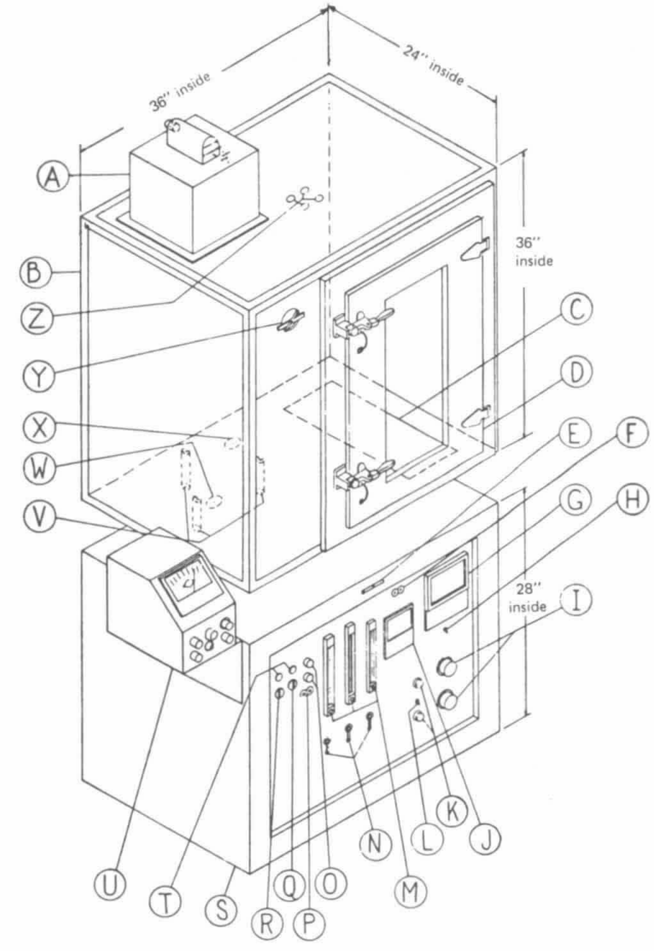
NOTE: Commercially available panels of porcelain-enamel steel (interior surface) permanently laminated to asbestos-cement board and backed with galvanized steel (exterior surface), with a total thickness $\frac{3}{16}$ in. (4.76 mm), have been found suitable.

2-2.2 The interior surfaces shall consist of porcelain-enameled metal or equivalent coated metal, resistant to chemical attack and corrosion, and suitable for periodic cleaning.

2-2.3 Sealed openings shall be provided to accommodate a vertical photometer, power and signal connectors, air and gas supply tubes, exhaust blower, inlet and exhaust vents, pressure and gas sampling taps, a pressure relief valve, a rod for remote positioning of the specimen holder, an aluminum foil [0.0010 in. (approx. 0.025 mm) or less] safety blowout panel at least 125 in.^{2} (806 cm^2) in area, and a hinged front-mounted door with an observation port or window.

2-2.4 All openings shall be located on the floor of the chamber.

Exception: The gas sampling taps, the positioning rod, and an inlet vent.



A — Phototube Enclosure
B — Chamber
C — Blowout Panel
D — Hinged Door with Window
E — Exhaust Vent Control
F — Radiometer Output Jack
G — Temperature (Wall) Indicator
H — Temperature Indicator Switch
I — Autotransformers
J — Voltmeter (furnace)
K — Fuse Holders
L — Furnace Heater Switch
M — Gas & Air Flowmeters
N — Gas & Air Shutoff Valves
O — Light Intensity Controls
P — Light Voltage Measuring Jack
Q — Light Source Switch
R — Line Switch
S — Support Frame
T — Indicating Lamps
U — Photometer Readout
V — Rods
W — Glass Window
X — Exhaust Vent
Y — Inlet Vent
Z — Access Ports

For SI Units: 1 in. = 25.4 mm.

Figure 2-1(b). Smoke Density Chamber Assembly.

2-2.5 When all openings are closed, the chamber shall be capable of developing and maintaining positive pressure during test periods, in accordance with Section 2-10.

2-3 Radiant Heat Furnace.

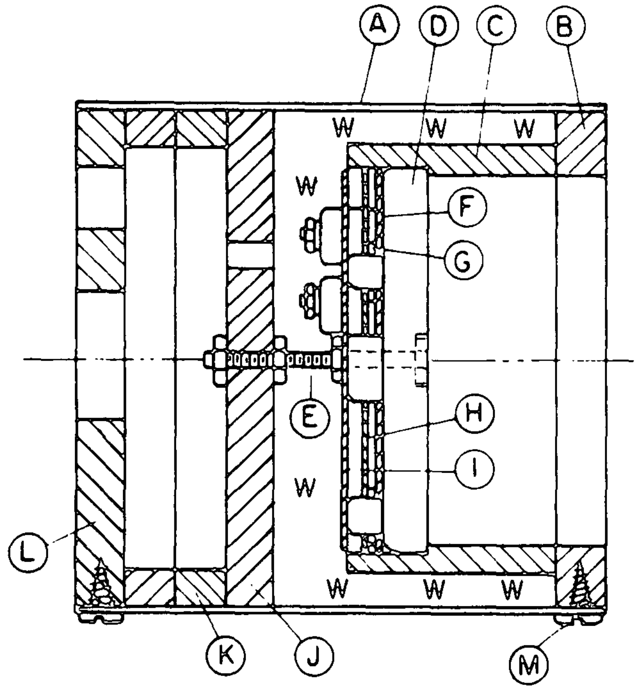
2-3.1 An electric furnace, as shown in Figure 2-3, with a 3-in. (76.2-mm) diameter opening shall be used to provide a constant irradiance on the specimen surface.

2-3.2 The furnace shall be located along the center line, equidistant between the front and back of the chamber, with the opening facing toward and about 12 in. (305 mm) from the right wall.

2-3.3 The center line of the furnace shall be about 7¾ in. (195 mm) above the chamber floor.

2-3.4 Furnace Control System.

2-3.4.1 The furnace control system shall maintain the required irradiance level under steady-state conditions with the chamber door closed to within ± 0.04 Btu/sec ft^2 (± 0.05 W/cm^2) for 20 minutes.



A — Stainless Steel Tube
B — Asbestos Board
C — Ceramic Tube
D — Heating Element, 525 W
E — Stainless Steel Screw
F — Asbestos Paper Gasket
G — Stainless Steel Spacing Washers (3)
H — Stainless Steel Reflector
I — Stainless Steel Reflector
J — Asbestos Board
K — Asbestos Board Rings
L — Asbestos Board Cover
M — Sheet Metal Screws
W — Pyrex Glass Wool

Figure 2-3 Furnace section.

2-3.4.2 The control system shall consist of an autotransformer or alternate control device and a voltmeter or other means for monitoring the electrical output.

NOTE: Where line voltage fluctuations are present, a constant-voltage transformer may be required to maintain the prescribed irradiance level.

2-4 Specimen Holder. Specimen holders shall conform in shape and dimension to that shown in Figure 2-4, and shall be fabricated to expose a 2⁹⁄₁₆ in. by 2⁹⁄₁₆ in. (65.1 mm by 65.1 mm) specimen area. Also shown in Figure 2-4 are the spring and rods for retaining the specimen within the holders.

2-5 Framework for Support of the Furnace and Specimen Holder. The furnace and specimen supporting framework shall be constructed essentially in accordance with Figure 2-5.

2-6 Photometric System.

2-6.1 The photometric system shall consist of a light source and photodetector, oriented vertically to reduce variations in measurement brought about by stratification of the smoke generated by materials under test.

2-6.2 The system shall be as shown in Figures 2-6(a) and 2-6(b) and include the following:

(a) The *light source* shall be an incandescent lamp operated at a fixed voltage in a circuit powered by a voltage regulating transformer. The light source shall be mounted in a sealed and light-tight box located below the chamber. This box shall contain the necessary optics to provide a collimated light beam passing vertically through the chamber.

(b) The *photodetector* shall be a photomultiplier tube, with an S-4 spectral sensitivity response and a dark current less than 10^{-9}A. A sealed box located directly opposite the light source shall be provided to house the photodetector and the focusing optics. A glass window shall be used to isolate the photodetector and its optics from the interior of the chamber.

2-7 Radiometer.

2-7.1 The radiometer for standardizing the output of the radiant heat furnace shall be of the circular foil type, the operation of which was described by Gardon. (See R. Gardon, "An Instrument for the Direct Measurement of Intense Thermal Radiation," *Review of Scientific Instruments*.)

2-7.2 The construction of the radiometer shall be as shown in Figure 2-7.

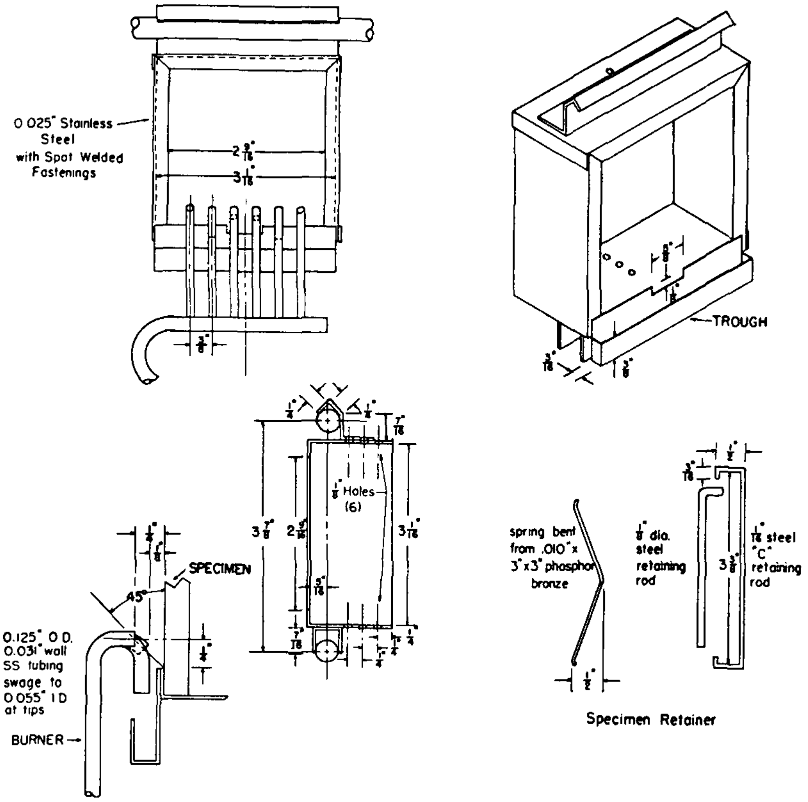
2-7.3 The radiometer shall have a stainless steel reflective heat shield with a 1½-in. (38.1-mm) aperture on the front and a finned cooler supplied with compressed air mounted on the rear to maintain a constant body temperature of 200 ± 5 °F (93 ± 3 °C).

2-8 Thermocouples for Determining Chamber Wall Temperature. A thermocouple shall be provided for determining the chamber wall temperature prior to testing.

2-9 Portable Recorder or Readout Meter.

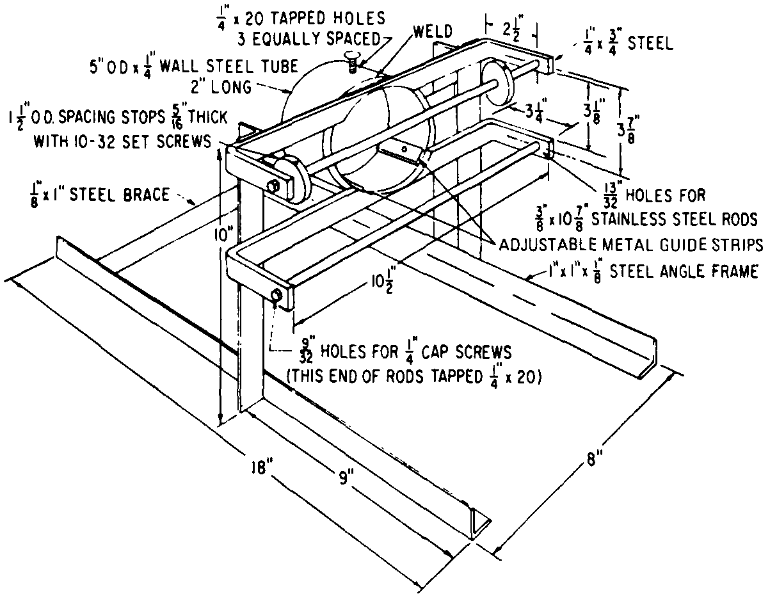
2-9.1 The outputs of the radiometer and the thermocouples shall be monitored by a suitable recorder or readout meter.

2-9.2 The photodetector output shall be recorded or monitored with a potentiometer or other suitable instrument capable of measurement over a range of 5 decades or more. (*See A-1.4.*)



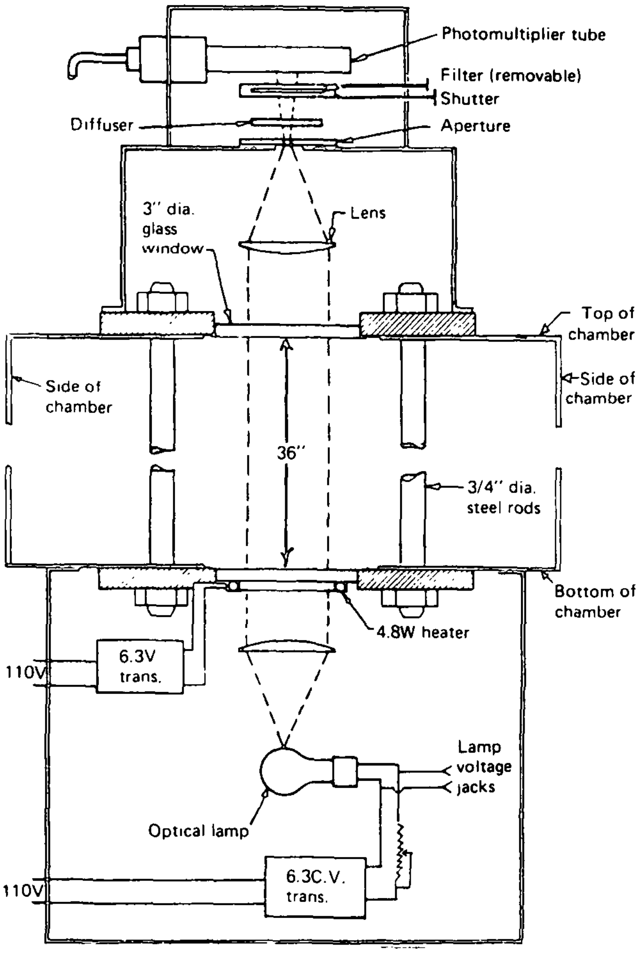
For SI Units: 1 in. = 25.4 mm.

Figure 2-4 Details of specimen holder and pilot burner.



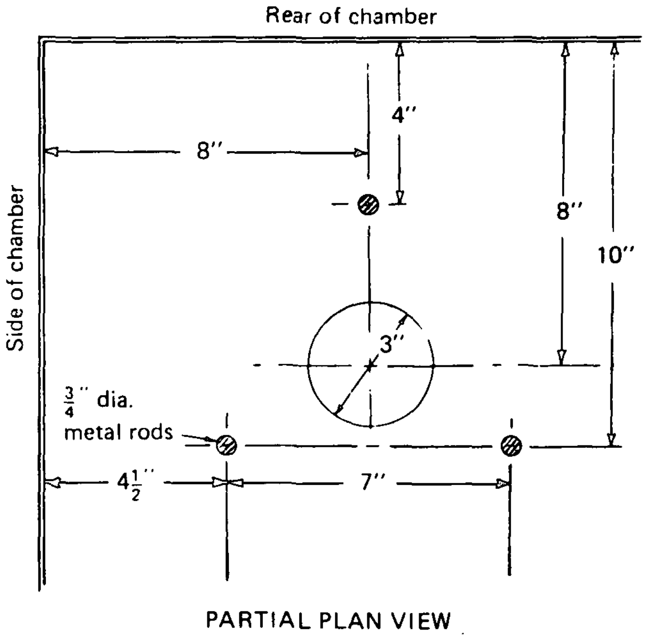
For SI Units: 1 in. = 25.4 mm.

Figure 2-5 Furnace support.



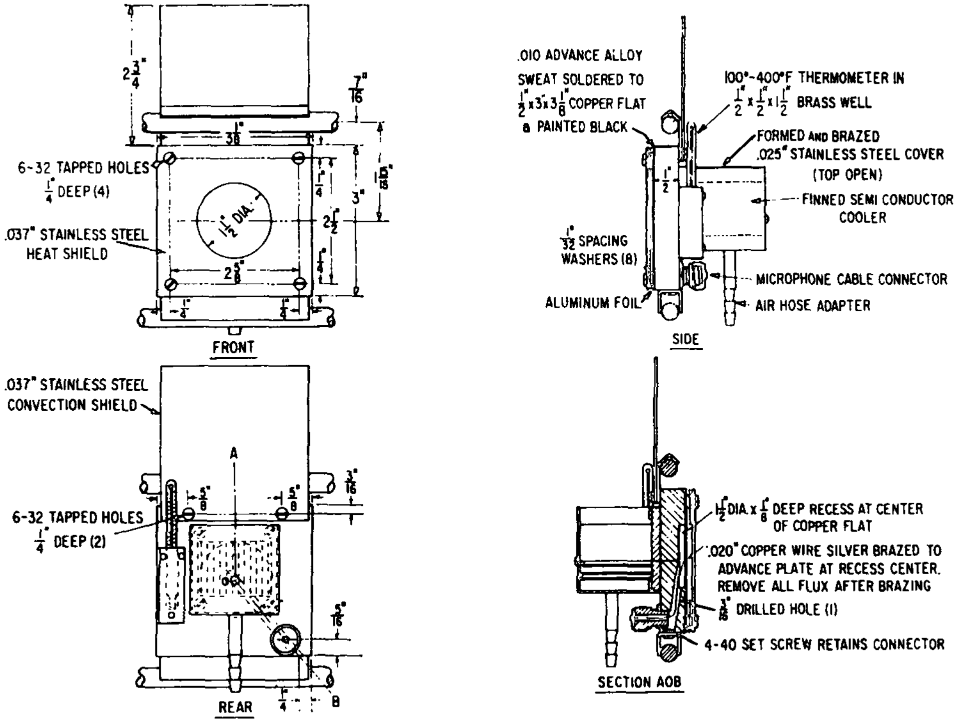
For SI Units: 1 in. = 25.4 mm.

Figure 2-6(a) Photometer details.



For SI Units: 1 in. = 25.4 mm.

Figure 2-6(b) Photometer location.



For SI Units: 1 in. = 25.4 mm.

Figure 2-7 Radiometer detail.

2-10 Manometer for Chamber Pressure Measurements.

2-10.1 A simple water manometer with a range up to 6 in. (152 mm) of water shall be provided to monitor chamber pressure and leakage. (*See A-2.3.*)

2-10.2 The pressure measurement point shall be through a gas sampling hole at the top of the chamber.

2-10.3 A simple water column or relief valve shall be provided to permit control of chamber pressure. (*See A-1.8.*)

2-11 Multiple Flamelet Burner with Premixed Air-Propane Fuel.

2-11.1 For a flaming exposure test, a six-tube burner, with construction details as shown in Figure 2-4, shall be used.

2-11.2 The burner shall be centered in front of and parallel to the specimen holder.

2-11.3 The tips of the two horizontal tubes shall be centered ¼ ± 1/16 in. (6.4 ± 1.6 mm) above the holder edge and ¼ ± 1/16 in. (6.4 ± 1.6 mm) away from the specimen surface.

2-11.4 Provision shall be made to rotate or move the burner out of position during nonflaming exposures.

2-11.5 A premixed air and propane (95 percent purity or better) test gas shall be used.

2-11.6 The air and propane shall be metered by calibrated flow meters and needle valves at 500 cm^3/min. for air and 50 cm^3/min. for propane.

Chapter 3 Test Specimens

3-1 Specimen Description.

3-1.1 Size.

3-1.1.1 The test specimens shall be 3 in. by 3 in. ± 0.03 in. (76.2 mm by 76.2 mm ± 0.7 mm) by the intended installation thickness up to and including 1 in. (25.4 mm) thickness.

3-1.1.2 Specimens provided in thicknesses in excess of 1 in. (25.4 mm) shall be sliced to 1 in. (25.4 mm) thickness and the original (uncut) surface tested.

3-1.1.3 Multilayer materials greater than 1 in. (25.4 mm) thick, consisting of a core material with surface facings of different materials, shall be sliced to 1 in. (25.4 mm) thickness, and each original (uncut) surface shall be tested separately if required under 3-1.3.

3-1.2 Specimen Orientation.

3-1.2.1 If visual inspection of the specimen indicates a pronounced grain pattern, process-induced surface orientation, or other nonisotropic property, the specimen shall be tested in two or more orientations.

3-1.2.2 The highest smoke density value and the test orientation shall be stated.

3-1.3 Specimen Assembly.

3-1.3.1 The specimen shall be representative of the material or composite and shall be prepared in accordance with recommended application procedures.

NOTE: Substrate or core materials for the test specimens should be the same as those for the intended application. Where a material or assembly may be exposed to a potential fire on either side, both sides should be tested.

Exception: Flat sections of the same thickness and composition may be supplied and tested in place of curved, molded, or specialty parts.

3-1.3.2 Where an adhesive is intended for field application of a finish material to a substrate, the prescribed type of adhesive and its spreading rate shall be noted and used for test.

3-1.3.3 When supplementary tests are necessitated by delamination, cracking, peeling, or other separations affecting smoke generation, the manner of performing such supplementary tests, and the test results, shall be included in the report with the conventional test.

NOTE: Finish materials, including sheet laminates, tiles, fabrics, and others secured to a substrate material with adhesive, and composite materials not attached to a substrate, may be subject to delamination, cracking, peeling, or other separations affecting their smoke generation. To evaluate these effects, supplementary tests, performed on a scored (slit) exposed surface or on interior layers or surfaces, may be necessary.

3-1.3.4 For comparative tests of finish materials without a normal substrate or core and for screening purposes only, the following procedures shall be employed:

(a) Rigid or semirigid sheet materials shall be tested by the standard procedure regardless of thickness.

(b) Liquid films (paints, adhesives, etc.), intended for application to combustible base materials, shall be applied to the smooth face of ¼ in. (6.4 mm) thick tempered hardboard, nominal density 50 to 60 lb/ft^3 (0.8 to 0.97 g/cm^3), using recommended (or practical) application techniques and coverage rates. Tests shall also be conducted on the hardboard substrate alone, and these values shall be recorded as supplemental to the measured values for the composite specimen.

(c) Liquid films (paints, adhesives, etc.), intended for application to noncombustible substrate materials, shall be applied to the smooth face of ¼ in. (6.4 mm) thick asbestos-cement board, nominally 120 lb/ft^3 (1.9 g/cm^3) in density, using recommended (or practical) application techniques and coverage rates.

3-2 Number of Test Specimens. Three tests under flaming exposure and three tests under nonflaming exposure shall be conducted on each material (total of six specimens) in accordance with the conditions described herein.

3-3 Specimen Conditioning. Specimens shall be predried for 24 hours at 140 ± 5 °F (60 ± 3 °C), then conditioned to equilibrium (constant weight) with an ambient temperature of 73 ± 5 °F (23 ± 3 °C) and a relative humidity of 50 ± 5 percent.

3-4 Specimen Mounting.

3-4.1 All specimens shall be covered across the back, along the edges, and over the front surface periphery with a single sheet of aluminum foil (0.0015 ± 0.0005 in., or approximately 0.04 mm).

3-4.2 Care shall be taken not to puncture the foil or to introduce unnecessary wrinkles during the wrapping operation.

3-4.3 Foil shall be folded in a way to minimize losses of melted material at the bottom of the holder.

3-4.4 Excess foil along the front edges shall be trimmed off after mounting. A flap of foil shall be cut and bent forward at the spout to permit flow from melting specimens.

NOTE: Problems associated with interpretation of experimental results when unburned molten drips occur are discussed in Appendix C.

3-4.5 All specimens shall be backed with a sheet of asbestos millboard. (*See Section 2-4.*)

3-4.6 The specimen and its backing shall be secured with the spring and retaining rod. A modified C-shape retaining rod shall be used with specimens from ⅝ to 1 in. (15.9 to 25.4 mm) thick.

3-4.7 Flexible specimens shall not be compressed below their normal thickness.

3-4.8 It is the intent of this test method to maintain the prescribed exposure conditions on the specimen for the test duration. If under either the flaming or nonflaming exposure there is an excess of melted material that overflows the trough, the specimen area shall be reduced; e.g., if the area is reduced to 1½ in. wide by 3 in. high (38.1 mm by 76.2 mm) centrally located, the appropriate area shall be used in calculating D_s. (*See Section 5-1.*)

Chapter 4 Test Procedure

4-1 Test Room. All tests shall be conducted in a room or enclosed space having an ambient temperature of 73 ± 5 °F (23 ± 3 °C) and relative humidity of 50 ± 20 percent at the time of test. Precautions shall be taken to provide a means for removing potentially hazardous gases from the area of operation.

4-2 Equipment Cleaning.

NOTE: Charred residues on the specimen holder and horizontal rods should be removed to avoid contamination.

4-2.1 The chamber walls shall be cleaned whenever periodic visual inspection indicates the need.

NOTE: An ammoniated spray detergent and soft scouring pads have been found effective.

4-2.2 The exposed surfaces of the glass windows separating the photodetector and light source housing from the interior of the chamber shall be cleaned before each test. (Ethyl alcohol is generally effective.)

4-3 Warm-up of Furnace.

4-3.1 During the warm-up period all electric systems (furnace, light source, photometer readout, etc.) shall be on, the exhaust vent and chamber door closed, and the inlet vent open.

4-3.2 When the temperature on the center surface of the back wall reaches a steady-state value in the range of 95 ± 4 °F (35 ± 2 °C), the chamber is ready for furnace calibration or testing.

NOTE: To increase chamber wall surface temperature to the stated level under adverse conditions, an auxiliary heater may be used. Conversely, to decrease this temperature, the exhaust blower may be used to introduce cooler air from the laboratory.

4-3.3 The furnace output irradiance shall be calibrated, without the burner in place, at periodic intervals according to test experience (normally twice per test day).

4-3.4 A "blank" specimen holder, with the asbestos millboard exposed, shall always be directly in front of the furnace.

Exception: When displaced to the side by (1) the specimen holder during a test or (2) the radiometer during calibration.

The specimen holder shall be returned immediately to the above position when testing or calibration is completed.

4-3.5 During calibration, the radiometer shall be placed on the horizontal rods of the furnace support framework and accurately positioned in front of the furnace opening by sliding and displacing the "blank" specimen holder against the prepositioned stop. The furnace support framework, stop, and "blank" specimen holder shall provide for the horizontal and vertical centering within ± $\frac{1}{16}$ in. (1.6 mm) with respect to the furnace opening of the radiometer during calibration and of the loaded specimen holder during test.

4-3.6 With the chamber door closed and inlet vent opened, the compressed air supply to the radiometer cooler shall be adjusted to maintain its body temperature at 200 ± 5 °F (93 ± 3 °C).

4-3.7 The autotransformer setting shall be adjusted so as to obtain the calibrated millivolt output of the radiometer corresponding to a steady-state irradiance of 2.2 ± 0.04 Btu/sec ft^2 (2.5 ± 0.05 W/cm^2) averaged over the central 1½-in. (38.1-mm) diameter area.

4-3.8 The recorder or meter described in Section 2-9 shall be used to monitor the radiometer output. After the prescribed irradiance level has reached steady-state, the radiometer shall be removed from the chamber and replaced with the "blank" specimen holder.

4-3.9 After the system has reached steady-state conditions, the meter and/or recorder zero shall be adjusted.

4-3.10 The amplifier sensitivity shall be adjusted to obtain a full-scale reading of the photodetector (100 percent transmittance) on the recorder or readout meter.

4-3.11 The "dark current" (zero percent transmittance) on the maximum sensitivity range of the readout meter shall be determined by blocking the light, and the "dark current" reading shall be adjusted to zero.

4-4 Burner Positioning. For nonflaming exposures, the multiple flamelet burner shall be removed. For flaming exposures, the burner shall be positioned across the lower edge of the specimen as described in Section 2-11. (Check the burner distance relative to the "blank" specimen before fuel adjustment and ignition.)

4-5 Procedures. Before positioning the test specimen, the chamber shall be flushed for about 2 minutes with the door and exhaust and inlet vents open and the starting temperature of the chamber shall be verified using the procedure described in 4-3.1 and 4-3.2.

4-5.1 The exhaust vent and blower shall then be closed.

4-5.2 The loaded specimen holder shall be placed on the bar support and pushed into position in front of the furnace (with burner in position for flaming exposure) by displacing the "blank" holder.

4-5.3 The chamber door shall be quickly closed and the timer and/or recorder chart drive shall be simultaneously started. The inlet vent shall be closed completely only when the photometer indicates smoke.

4-5.4 Light transmittance and the corresponding time shall be recorded, either as a continuous plot with a multi-range recorder or at sufficient time intervals with a multi-range meter readout. (Make and note the necessary full-scale range changes in decade steps.)

4-5.5 The increase in chamber pressure shall be observed with the manometer described in Section 2-10. A regulator (*see A-1.8*) shall be used to maintain the pressure in the range of 4 ± 2 in. (100 ± 50 mm) of water during most of the test. If negative pressure develops after very intense specimen flaming, the inlet vent shall be opened slightly to equalize the pressure. As a result of pressure rise, the fuel and air valves shall be adjusted during the flaming test to maintain a constant flow rate.

4-5.6 Any observations pertinent to the burning and smoke generating properties of the material under test shall be recorded in accordance with Chapter 6.

4-5.7 The test shall continue for 20 minutes or until a minimum light transmittance value is reached, whichever occurs first. If the minimum light transmittance does not occur within the 20-minute exposure period, this shall be noted in reporting the results.

4-5.8 If transmittance falls below 0.01 percent, the chamber window shall be covered with an opaque screen to avoid possible light scattering effects from room light. Also, any supplementary optical filter in the photometer system shall be removed or displaced in order to extend the measuring range. (If extraneous light can reflect into the photometer during removal of the filter, turn the high voltage off or adjust the scale to minimize sensitivity. Replace the filter before exhausting smoke from the chamber.)

4-5.9 The burner on flaming exposures shall be extinguished and exhausting the chamber shall be initiated within one minute after reaching minimum transmittance. The specimen shall be displaced from the front of the furnace by pushing the "blank" specimen holder with the positioning rod. Exhausting shall continue with the inlet vent open until maximum transmittance is reached. (Record this transmittance value as the T_c, "clear beam" reading, which is to be used to correct for deposits on the photometer windows.)

NOTE: In some cases the transmittance may increase somewhat and subsequently decrease to the ultimate minimum transmittance.

Chapter 5 Calculations

5-1 Calculate specific optical density, D_s, from the percent light transmittance, T, caused by the smoke generated from an exposed specimen area, A, in the closed chamber of volume, V, and over a light path, L, as follows:

$$D_s = \frac{V}{AL}\left[\log_{10}\left(\frac{100}{T}\right)\right] = G\left[\log_{10}\left(\frac{100}{T}\right)\right]$$

where G represents the geometrical factor associated with the dimensions of the chamber and specimen. Corrections for the volume of the furnace assembly and the volume included in the door recess are generally less than 1 percent and may be neglected.

When it is necessary to remove the neutral density filter (*see A-1.4*) to measure low levels of light transmittance, the specific optical density appropriate for the filter shall be added. The value to be added is equal to the known optical density of the filter (*see A-2.1.3*) multiplied by G.

5-2 Calculate the maximum specific optical density, D_m, using the formula in Section 5-1 with a light transmittance corresponding to the minimum level reached during the test. Correct all maximum specific optical density values by subtracting the specific optical density equivalent for soot and other deposits on the photometer windows. The "clear beam" transmittance reading T_c is used to calculate a specific optical density equivalent D_c, using the same formula but with different subscript. A corrected maximum specific optical density calculation is expressed as follows:

$$D_m\,(\text{corr.}) = D_m - D_c$$

5-3 For systems without "dark current" cancellation, a correction shall be made for any percent light transmittance reading T, approaching the dark current value T_d.

The corrected percent light transmittance T′ shall be obtained from:

$$T' = 100\left[1 - \frac{100 - T}{100 - T_d}\right] = 100\left[\frac{T - T_d}{100 - T_d}\right]$$

and shall be used for the specific optical density calculations described in Sections 5-1 and 5-2.

Chapter 6 Report

6-1 The report (*see Appendix B*) shall include the following:

(a) Complete description of the specimen tested including: type, manufacturer, shape, thickness and/or other appropriate dimensions, weight or density, coloring, etc.

(b) Complete description of the test specimens, including: substrate or core, special preparation, mounting, etc.

(c) Test specimen conditioning procedure.

(d) Number of specimens tested.

(e) Test conditions: Type of exposures, type of holder used, exposure period.

(f) Observations of the burning or smoldering characteristics of the specimens during test exposure, such as delamination, sagging, shrinkage, melting, collapse, etc.

(g) Observations of the smoke generating properties of the specimens during exposure, such as color of the smoke, nature of the settled particulate matter, etc.

NOTE: Analysis of products of combustion. Although not specifically required as part of the method, products of combustion may be drawn from the chamber at various times during the progress of the test for analysis. The physical properties of the smoke may be investigated by electrostatic or impact collection and various methods of particle analysis. The presence and concentrations of various toxic and irritating gaseous products may be determined using colorimetric gas detector tubes, gas chromatography methods, ion-selective electrodes, or other techniques.

(h) A record of the geometrical factor, G, as calculated from measured values of chamber volume, V, photometer light path length, L, and exposed specimen area, A. (*See Chapter 5, Calculations.*)

(i) Test results calculated as described in Chapter 5, including the average and range on each set of specimens for D_m (corr.), and D_c. Sufficient test results should allow development of a smooth curve of D_s versus time.

6-2 If the test is terminated on the basis of a 20-minute exposure limitation, this fact shall be noted when reporting measurements observed at that time.

Appendix A Apparatus Construction and Calibration

This Appendix is not a part of the requirements of this NFPA document, but is included for information purposes only.

A-1 Construction Details.

A-1.1 Radiant Heat Furnace. (*See Section 2-3.*) The furnace consists of a coiled wire or other suitable electrical heating element (525 W or greater) mounted vertically in a horizontal ceramic tube 3 in. (76.2 mm) i.d. by 3⅜ in. (85.7 mm) o.d. by 1⅝ in. (41.3 mm) long. The tube is bored out at one end to 3¹⁄₃₂ in. (77.0 mm) i.d. and to a depth of ⅝ in. (15.9 mm) to accommodate the heating element. A ¹⁄₁₆-in. (1.6-mm) asbestos paper gasket and three stainless steel reflectors are mounted behind the heating element. A ⅜-in. (9.5-mm) asbestos millboard disc, provided with ventilation and lead wire holes, is positioned behind the heating element and used to center the assembly with respect to front ⅜-in. (9.5-mm) asbestos millboard ring by means of a 6-32 stainless steel screw. The adjustment nuts on the end of the centering screw provide proper spacing of the furnace components. The cavities adjacent to the heating element assembly are to be packed with glass wool. The furnace assembly is housed in a 4 in. (102 mm) o.d. by 0.083 in. (2.1 mm) wall by 4⅛ in. (105 mm) long stainless steel tube. Two additional ⅜-in. (9.5-mm) asbestos board spacing rings and a rear cover of ⅜-in. (9.5-mm) asbestos board complete the furnace. The furnace is to be located centrally along the long axis of the chamber with the opening facing toward and about 12 in. (305 mm) from the right wall. The center line of the furnace is about 7¾ in. (195 mm) above the chamber floor.

A-1.2 Specimen Holder. (*See Section 2-4.*) The specimen holder is to conform in shape and dimension to Figure 2-4 and to be fabricated by bending and brazing (or spot welding) 0.025 in. (0.6 mm) thick stainless steel to provide a 1½-in. (38.1-mm) depth, and to expose a 2⁹⁄₁₆-in. by 2⁹⁄₁₆-in. (65.1-mm by 65.1-mm) specimen area. As described in Section 2-5, the holder is to have top and bottom guides to permit accurate centering of the exposed specimen area in relation to the furnace opening. A 3-in. by 3-in. (76.2-mm by 76.2-mm) sheet of ½-in. (12.7-mm) asbestos millboard, having a nominal density of 50 ± 10 lb/ft^3 (0.85 ± 0.17 g/cm^3), is to be used to back the specimen. A spring bent from 0.010 in. (approximately 0.25 mm) thick phosphor bronze sheet is to be used with a steel retaining rod to securely hold the specimen and millboard backing in position during testing.

A-1.3 Support of Furnace and Specimen Holder. (*See Section 2-5.*) The framework as shown in Figure 2-5 has welded to it a 5 in. (127 mm) o.d., ¼ in. (6.4 mm) wall, 2 in. (50.8 mm) long, horizontally oriented steel tube to support the radiant heat furnace described in Section 2-3. This support tube is to have provision to accurately align the furnace opening so that it is: (1) 1½ in. ± ¹⁄₁₆ in. (38.1 mm ± 1.6 mm) away from, (2) parallel to, and (3) centered horizontally and vertically to within ± ¹⁄₁₆ in. (1.6 mm) with respect to the exposed specimen area. Three tapped holes with screws equidistantly positioned around the furnace support tube, or one screw at the top of the support in conjunction with two adjustable (vertically along the support tube) metal guide strips mounted horizontally inside to the tube, are to provide adequate alignment.

The framework is to have two ⅜-in. (9.5-mm) diameter transverse rods of stainless steel to accept the guides of the specimen holder described in A-1.2. The rods are to support the holder so that the exposed specimen area is parallel to the furnace opening. Spacing stops are to be mounted at both ends of each rod to permit quick and accurate lateral positioning of the specimen holder.

A-1.4 Photometric System. (*See Section 2-6.*) The photometric system is to consist of a tungsten-filament light source (Type 1630 6.5 volt lamp, maintained at 4 ± 0.2 V) and a photodetector with an S-4 spectral sensitivity response. The photometer is to be oriented vertically to reduce variations in measurement brought about by stratification of the smoke generated by the specimens under test. The system is shown in Figures 2-6(a) and 2-6(b). The window in the chamber floor through which the light beam passes is provided with an electric heater to maintain a temperature of at least 125 °F (52 °C) to minimize smoke condensation. The collimated beam inside the chamber is to have a path length of 36 ± ⅛ in. (914 ± 3 mm). The approximately circular light "spot" is centered entirely within the sensing area of the detector. A typical photomultiplier photometer system will require a high-voltage dc power supply and a neutral density filter of sufficient optical density to produce a convenient signal level for the indicator or recorder. The photometer system used is to be capable of permitting the recording of reliable optical densities of at least 6.0, corresponding to transmittance values of 0.0001 percent of the incident light. (*See A-2.1.1.*)

The two optical platforms and their housings shall be kept in alignment with three metal rods, ½ in. (12.7 mm) in diameter, fastened securely into 5⁄16 in. (7.9 mm) thick externally mounted top and bottom plates and symmetrically arranged about the collimated light beam.

A-1.5 Radiometer. (*See Section 2-7.*) The body temperature of the radiometer should be monitored with a 100-220 °F (38-100 °C) thermometer in a ½ in. by ½ in. by 1½ in. long (12.7 mm by 12.7 mm by 38.1 mm) brass well drilled to accept the thermometer with a close fit. Silicone grease may be used to provide good thermal contact.

The circular receiving surface of the radiometer should be spray-coated with an infrared-absorbing black paint containing a silicone vehicle. The radiometer is to be calibrated calorimetrically in accordance with the procedure summarized in A-2.2.

A-1.6 Chamber Wall Thermocouple. (*See Section 2-8.*) A thermocouple is mounted with its junction secured to the geometric center of the inner rear wall panel of the chamber using a ¼ in. (6.4 mm) thick polystyrene foam disk cover and epoxy cement.

A-1.7 Burner. (*See Section 2-11.*) The multiple flamelet burner is a six-tube burner, with construction details as shown in Figure 2-4.

The vertical tubes of the six-tube burner are made from ⅛ in. (3.2 mm) o.d. by 0.031 in. (0.8 mm) wall stainless steel tubing (two tubes are bent 180 degrees into the trough, two tubes are bent 135 degrees from the vertical, and two tubes are bent 90 degrees from the vertical).

All tubes should be crimped at the tip to reduce the opening diameter to 0.055 in. (1.4 mm). The horizontal manifold section of the burner consists of ¼ in. (6.4 mm) o.d. by 0.035 in. (0.9 mm) wall stainless steel tubing. The other end is attached to a fitting in the chamber floor.

A-1.8 Chamber Pressure Regulator. A simple pressure regulator consists of an open, water-filled bottle and a length of flexible tubing, one end of which is connected to a sampling port on the top of the chamber. The other end of the tubing is inserted 4 in. (102 mm) below the water surface. The bottle is located at the same level as the floor of the chamber.

A-2 Calibration of Test Equipment.

A-2.1 Photometric System.

A-2.1.1 When first assembled and as necessary following use or when suspicious of a malfunction, calibration of the photometer should be checked by interrupting the light beam with calibrated neutral density filters. The filters should cover the full range of the instrument. Optical density values measured by the photometer are to be within ± 3 percent of the calibrated values.

A-2.1.2 Shifts in dark current levels between tests, excessive zero shifts during test, or lack of calibration indicate the need for inspection of the photometer system.

A-2.1.3 The optical density of a supplementary filter used to extend the measuring range of the photometer is to be known to an accuracy of ± 3 percent.

A-2.2 Radiometer. Calibration of the radiometer is accomplished by placing it at suitable distances from a radiant energy source, while maintaining its body temperature at 200 ± 5 °F (93 ± 3 °C) with controlled airflow through the rear-mounted cooler, and measuring its electrical output as a function of the irradiance level. The irradiance level is determined calorimetrically by measuring the rate of temperature rise of a blackened thin copper disk of known weight, area [1½ in. (38.1 mm) diameter], specific heat, and absorptivity in place of the radiometer. The measured millivolt output of the radiometer, at a body temperature of 200 °F (93 °C), corresponding to an irradiance level of 2.2 ± .04 Btu/sec ft^2 (2.5 ± 0.05 W/cm^2) is used to establish the furnace control settings discussed in Sections 2-3, 4-3.1, and 4-3.2.

A-2.3 Chamber Pressure Manometer — Leak Rate Test. For purposes of standardization, a leakage rate test should be periodically conducted using the manometer and tubing described in Section 2-10. The chamber is pressurized to 3 in. (76 mm) of water by introducing compressed air through a gas sampling hole in the top. The decrease in pressure from 3 in. to 2 in. (76 mm to 50 mm) of water is timed with a stopwatch. This time should not be less than 5.0 minutes.

A-2.4 Standard Smoke Generating Materials. For checking operational and procedural details of the equipment and method described herein, two standard materials may be used. Under nonflaming conditions, a single layer of alphacellulose (cotton linters) paper, and under flaming conditions, plastic sheet should provide repeatable maximum specific optical density values in two portions of the measuring range. Use of these standard materials does not obviate the need for following the calibration and standardization procedure outlined in this standard.

NOTE: These reference samples, designated SRM 1006 and SRM 1007, may be purchased from the Office of Standard Reference Materials, National Bureau of Standards, Washington, DC 20234.

Appendix B

Suggested Report Form — Smoke Density Chamber

This Appendix is not a part of the requirements of this NFPA document, but is included for information purposes only.

Suggested Report Form — Smoke Density Chamber

Sample Code ______________ **Test No.** ______________ **Date** ________

Lab Code __________ **Operator** ____________________ **Time** ________

Recorded Data or Curve

Time, min.	% Trans.	D_s

Operating Conditions

Radiometer Reading __________ mV;
Irradiance __________ W/cm^2
Furnace Voltage __________ V
Burner Fuel __________ cc/min air;
__________ cc/min propane
Thermal Exposure: flaming smoldering
Chamber Pressure __________ inch H_2O
Chamber Wall Temp. __________ °C
Chamber Surface Condition __________

Burner: ☐ Standard ☐ Special

Sample

Description - ____________________
Manufacturer - ____________________
Preconditioning: Temp. __________ °C;
Duration __________ hr.
Conditioning: Temp. __________ °C;
RH __________ %; Duration. __________
Thickness - ______ in.; Density ______ g/cm^3 or lb/ft^3
Initial Wt. ________; Final Wt. ________;
% Loss __________
Special Conditions - ____________________

Results

Min. Trans. __________ % at __________ min
Max. Specific Optical Density, D_m = ______
Clear Beam Reading = ______________ %;
Equiv. D_c ______________
D_m (corr.) = $D_m - D_c$ = __________

Remarks

Appendix C Commentary

This Appendix is not a part of the requirements of this NFPA document, but is included for information purposes only.

C-1 Introduction. The smoke density chamber test was developed at the National Bureau of Standards and was first described in an ASTM research symposium in 1967. (1,9) Since that time, there have been numerous publications reporting on its application and on studies of the correlation of results of interlaboratory tests through its use. (2,3,4,5,6,7,8)

C-1.1 The method is somewhat like the box-type test developed by Rohm and Haas. (9,10) However, it provides certain modifications in the nature of specimen exposure and the capability for quantitative measurement of the smoke produced. Advantages provided by use of this test method include: (1) the smoke collection chamber is essentially sealed so all smoke produced during a test is retained; (2) only one surface of a test specimen is exposed to fire or radiant heating, thus providing a measure of effectiveness of surface treatment assisting in control of smoke release; (3) a vertical photometer is used as a means for avoiding measurement errors resulting from smoke stratification; (4) provision is included for reporting the result of smoke measurements in terms of specific optical density, which is a measurement of the amount of smoke produced and hence is useful for comparing one composition of a material against another.

C-1.2 Measurements made with the test relate to light transmission through smoke.

C-2 Features of Test Method.

C-2.1 Two exposure conditions can be simulated by the test: (1) radiant heating in the absence of ignition, and (2) an open flaming combustion of the specimen in the presence of supporting radiation. These two conditions were selected as representative of two types of fire involvement. The irradiance level of 2.5 W/cm^2 was selected as the highest for which most cellulosics would pyrolize without self-ignition. This irradiance level is much lower than that which would exist in a compartment after flashover. It more nearly simulates conditions in the initial stages of a fire.

C-2.1.1 From a scientific viewpoint, it would be desirable to have constant irradiance over all portions of the specimen. From a practical point of view, this was not feasible because size and heat input of the furnace would have to be greatly increased. It was considered, therefore, more practical to accept a modest nonuniformity of irradiance across the surface of the specimen. This is not defined in terms of radiance units, but rather by specifying the dimensions of the furnace geometry and the specimen spacing. Thus, radiant configuration geometry was selected as a means of specifying the variability of surface irradiance. The average irradiance specified in the test method is that measured by the radiometer described in the standard, an instrument sensitive only to the 1½-in. (38.1-mm) diameter central area of the specimen holder.

C-2.2 Figure C-1 shows the result of one survey of irradiance across the specimen diagonal. This suggests that the overall average effective flux level during nonflaming pyrolysis is probably about 2.3 W/cm^2. While this degree of nonuniformity is short of technical perfection, it is accepted as a practical compromise, considering the use for which the test method is intended.

C-2.2.1 The primary measurement made during the conduct of the test is of the amount of light transmitted as a fraction or percentage of the initial light transmitted

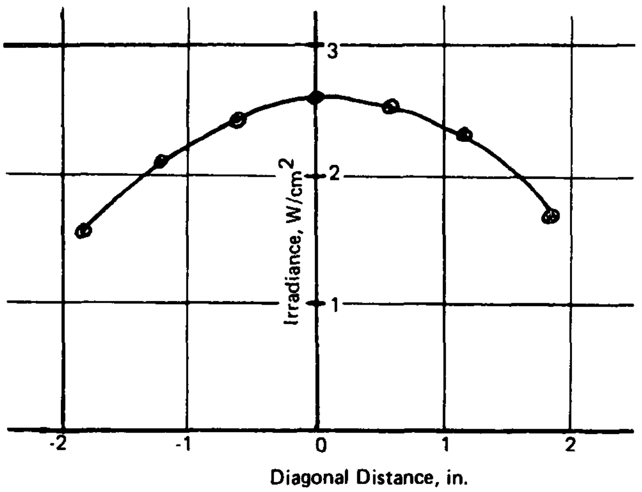


Figure C-1 Diagonal survey of irradiance at specimen during operation at nominal 2.5 W/cm².

by the optical system. The minimum percent light transmitted value is, in turn, used to calculate the maximum specific optical density, D_m, value, in accordance with Chapter 5 of this standard. There is some advantage to using specific optical density as a value by which to evaluate results as compared to using percent light transmittance.

C-2.2.2 The use of this unit of smoke measurement is based on Bouguer's law of light attenuation, which is expressed as follows:

$$T = Toe^{-\sigma L}$$

where:

T = % flux transmittance,

To = 100, the initial transmitted flux,

σ = attenuation coefficient,

L = length of the optional path, and

e = 2.7183.

C-2.2.3 While the smoke produced from fire usually does not meet the requirement of a monodispersed aerosol, it has been found to behave in a photometric manner such that, for purposes intended, optical density may be considered to be roughly proportional to the smoke particulates produced. The measurement unit, specific optical density, D_s, has been introduced to provide a conveniently factored rating scale as follows:

$$D_s = (V/AL)d$$
$$= (V/AL) \log (100/T) \text{ where } (V/AL) = 132.$$

Previous draft versions of this test method have proposed that, in the situation that the smoke produced exceeds the measurement capability of the apparatus, or if only small specimens were available, specimens less than standard size could be tested and the results extrapolated to the standard specimen size. This procedure should not be used for several reasons, one of which involves the nonuniformity of irradiance and pilot flame exposure.

C-2.2.3.1 Certain other test methods report smoke simply in terms of light transmission. The problem of such a procedure is that one not familiar with the characteristics of smoke aerosols might assume that the percent light transmittance is a reciprocal, linear function of the quantity of smoke produced; that is, making the assumption that as the quantity of smoke produced is doubled, the percent light transmittance is cut in half. This is incorrect.

C-2.2.4 The concept of specific optical density, while old in terms of chemical photometric practice, was first introduced for measuring smoke as part of the smoke density chamber test method. It is based on Bouguer's law and permits reporting smoke development in terms that recognize the area of the specimen involved, the volume of the box, and the optical path length of the photometer. Specific optical density is without dimension. Its value must, however, be recognized as relating to the specimen only in the thickness tested. In theory, it has the unique advantage of providing a basis for estimating the smoke optical density or light-obscuring properties of smoke that can be developed by the same assumption of uniform smoke-air mixing and under similar fire exposure conditions. At the present time, techniques for using this theoretical approach have not been developed to a practical stage because of (1) variations in types of fire exposure, (2) the rate of involvement of a material in a fire, (3) the ventilation characteristics of the compartment, and (4) the degree of stratification of the accumulated smoke. These are, in most instances, undetermined variables which greatly influence light transmission through smoke resulting from a fire.

C-3 Factors Influencing the Test. During development of the test method, many factors were considered that could influence the measurements. Some of the more important of these are mentioned and briefly discussed in the following paragraphs.

C-3.1 It was observed that, in spite of significant thermal convection mixing, smoke near the top of the cabinet was obviously more dense. This fact was verified by experimental measurements. As a result, it was apparent that a vertical photometer would yield a much more representative measurement of smoke accumulation than would be provided by a horizontal unit at one position in the chamber.

C-3.2 Experiments showed that the optical density of the accumulated smoke was sensitive to the spacing between the specimen face and the plane of the furnace opening. The experiments seem to suggest that the sensitivity was caused by two effects—close spacing caused more smoke to enter the furnace and become consumed there; it also reduced air circulation past the specimen and thus inhibited open flaming combustion. As a result, the separation called for in A-1.3 of 1½ ± 1/16 in. (38.1 ± 0.8 mm) was selected as a fair compromise for the purpose of standardization. If this spacing is not held, a small systematic change should be expected in smoke measurement. Similarly, it is necessary to maintain the specified spacing of 3.0 ± 1/32 in. between the heater face and the specimen surface.

C-3.3 The use of aluminum foil to wrap the back and edges of the specimen was introduced to provide better standardization because it was found that if smoke was allowed to leak out the back and edges of the specimen holder, the various ways this could occur introduced an undesirable variability in the measurements.

C-3.4 The question of how to assess, in an equitable fashion, the smoke production of thermoplastics has been a vexing one since early development of the test. The decision to use a vertical specimen orientation was based on knowledge that fire behavior and thus smoke production would differ in vertical and horizontal arrangement positions. Since the method was considered most likely to be used for experimental evaluation of interior wall finished products, the vertical specimen position was selected as most relevant. Obviously, the thermoplastic problem remained. Portions of such materials were found in varying degrees to melt and drip to the floor of the chamber. Thus, the smoke resulting from such materials is less than would be expected if all the material remained in the flux field. Whether such materials should be penalized or credited for such behavior has not been validated by definitive experimental and theoretical studies. In spite of this uncertainty, during the latter development stages of the test methods, a decision was reached to provide a trough on the specimen holder to collect and permit consumption of some of the molten residue. In processing this standard, questions were raised as to the usefulness of the trough, since the thermal exposure to the material within it is less severe than that to material that remains in the normal specimen position. A small-scale study was conducted. It showed that thermoplastic materials differed widely. Whereas appreciable smoke developed from one material placed in the trough, only a small quantity of smoke developed when another material was placed in the trough. This did not seem, however, to be too different from that performance which might be expected from the same materials in another fire exposure, and thus there does not seem to be any reason to ban from the test thermoplastic materials that melt or drip into the trough.

C-4 Precision.

C-4.1 In any method, one of the important considerations is the degree to which it, when applied to a given material, will yield constant results. Since this test results in destruction of the specimen, the results of any test to determine precision are affected not only by the random errors that might be inherent in the procedure but also by any variation in the properties of the replicate specimens. Thus, in studying the degree to which experimental results can be repeated within a given laboratory, it is desirable to use a material from which specimens of uniform composition and dimensional characteristics can be prepared.

C-4.1.1 This fact was recognized in planning the large interlaboratory study of precision of the measurement method. In spite of this, some of the experimental variability observed was undoubtedly related to variations in the replicate specimens. In at least one instance, variation in thickness as great as 20 percent was observed. To assist in identifying variability resulting from this cause, requirements for weighing specimens have now been included as a part of the test procedure.

C-4.2 Various changes were made in the test method description as adopted, as compared to the description used to advise for the round-robin test conducted. These included: (1) running additional samples when the results of three specimens are highly variable, (2) maintenance of pilot burner, (3) deletion of data that are inconsistent with the equipment, and (4) improved calibration and alignment procedures. These changes are such that the precision data given should be assumed to be conservative as they relate to the test method adopted. Better precision might be expected if another laboratory round-robin test should be conducted.

C-4.2.1 When studying the results reported by the various laboratories participating in the round-robin study, it was realized that the test method draft given to the laboratories to follow failed to contain a section describing conditions under which data obtained from the test should be excluded. For instance, certain materials were found to ignite under the nonflaming exposure condition. Obviously, these were not nonflaming results. Another cause for such questioning of data involved results that exceeded the measurement capability of the photometer.

C-5 Reporting of Results. One of the obvious needs with a test method of this type is to consider ways in which the experimental data should be reported. Early draft versions of this standard contained a recommendation that a correction be applied to the measured D_m (corr.). The reporting of D_m as a preferred measurement result is based on the following facts:

C-5.1 The deposit remaining following a test represents a part of the smoke produced. Thus, it seems irrational to subtract this unless it can be shown that the deposit results from late accumulation following a peak smoke reading. The procedures of the test method seem to make this unlikely.

C-5.2 Experience has shown that the determination of T used eventually to calculate D_m (corr.) is subject to variations in operator technique during the chamber venting procedure.

C-5.3 The introduction of the correction, while not in itself a significant technical problem, suggests a technical sophistication that simply is not justified on the basis of intended use of the data. The effect of these facts was noticed during analysis of the round-robin experimental data. The results were found to be more consistent for the uncorrected data (D_m).

C-6 Limitations on Application of Smoke Measurement Data.

C-6.1 The smoke problems that develop during unwanted fires have been recognized for many years. Fire fighters are faced with them daily in their work. However, three problems have tended to prevent application of standards limiting the acceptability of materials or products on the basis of smoke production:

(a) The extent to which the smoke measurement assesses the smoke hazard. (12,13)

(b) The lack of a well-defined measurement method that could be shown to provide a technically valid means for smoke characterization.

(c) Most materials or products, when burning, release large quantities of smoke, and there have been only limited ways of reducing smoke production.

C-6.1.1 The first problem still exists.

C-6.1.2 The second problem has been partially alleviated with the development of the smoke chamber. However, it must be recognized that only two of a wide range of fire exposure conditions are simulated by the test method. Thus any rank ordering of materials by the test must be recognized as only based on the fire exposure conditions applied and, in fact, the test method develops different rankings depending upon whether a ranking is based upon the nonflaming exposure or the flaming exposure. All of the parameters that affect fire behavior will influence the amount of smoke produced. Thus, it is unrealistic to place great confidence in the smoke measurement as a unique and absolute measure of smoke production during building fires.

C-6.1.3 The third problem also still remains. If significant changes in smoke levels are to be expected when fire occurs it seems necessary to require large changes in D_s. To limit the type and size of fire that could develop, very severe limitations would have to be placed on smoke production of both the building finish material and the occupancy items, and comprehensive fire prevention and protection measures must be continually maintained.

C-6.2 It is important to remember that for any given thermal exposure condition, the smoke produced when a fire occurs is related to the thickness and density of material involved. The importance of specimen thickness is illustrated in Figure C-2. The indication deviations from a linear relationship of D_m with specimen thickness result from the decreasing pyrolysis rate of the specimen as the burning layer progresses into the specimen and, also, from the increasing rate of smoke dropout and condensation as high smoke concentration develops.

C-6.3 The smoke density chamber provides a means for characterizing smoke production for research and development only. It provides a means for reporting an experimental rate of smoke production and time at which specific smoke levels are reached under the test conditions applied.

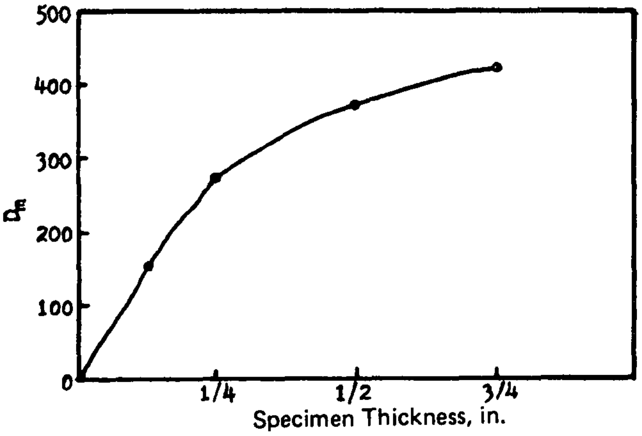


Figure C-2 **D_m for spruce as a function of specimen thickness under nonflaming conditions.**

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(11) Robertson, A.F., "Estimating Smoke Production During Building Fires," *Fire Technology*, FITCA, Vol. II (May 1975) pp. 80-94.

(12) "The Control of Smoke in Building Fires — A State-of-the-Art Review," *Materials Research and Standards*, Vol. II, No. 4 (1971) pp. 16-24.

(13) Committee E-5, "A Report on Smoke Test Methods," *Standardization News* (August 1976) pp. 18-26.

Appendix D Selected Papers for Further Study

This Appendix is not a part of the requirements of this NFPA document, but is included for information purposes only.

D-1 General. The papers enumerated below have been selected as an introduction to a much broader list of documents relating to smoke problems during building fires. In selection of these references emphasis has been placed on USA and Canadian work. There is a considerable body of foreign language publications of great merit, but with one or two exceptions these have not been included.

D-1.1 Review Papers.

Autian, J., "Toxicology Aspects of Flammability and Combustion of Polymeric Materials," *Fire and Flam.* (July 1970) pp. 239-268.

Galbreath, M., "Fire in High Buildings," National Research Council of Canada, *Fire Study*, 21, NRC No. 10081 (Ottawa, April 1968).

Little, Arthur D., "Fire Gas Research Report," *NFPA Quarterly*, 45, 3 (Jan. 1952) pp. 280-306.

Wood, P.G., "The Behavior of People in Fire," Joint Fire Res. Org. *Fire Research Note No. 953* (Nov. 1972) p. 113.

D-1.2 Fire Gas and Smoke Hazard.

Bono, J. A., and Breed, B. K., "Smoke Ratings in Relation to Visual Observations," *Fire Technology*, 2, 2 (May 1966) pp. 146-158.

Fiorca, V.; Higging, E. A.; Thomas, A.A.; and Davis, H. V., "Acute Toxicity of Brief Exposures to HF, HCl, NO_2 and HCN with and without CO," *Fire Technology*, 8, 2 (May 1972) pp. 120-129.

Fristrom, R., *Annual Summary Report* (July 1972 to 30 June 1973), App. Phys. Lab., Johns Hopkins Univ., Rept. No. FPP A73 (Aug. 1973).

Jin, T., "Visibility Through Fire Smoke (Part 2, Visibility of Monochromatic Signs through Fire Smoke)," *Report of Fire Res. Inst. of Japan*, No. 33 (1971) pp. 31-48.

Shern, J. H., "Smoke Contribution Factor in Fire Hazard Classification of Building Materials," *Fire Test Methods — Restraint and Smoke* (1966) ASTM STP422, 1967.

Smith, E. E., "Evaluation of the Fire Hazard of Duct Materials," *Fire Technology*, 9, 3 (Aug. 1973) pp. 157-170.

Tsuchiya, Y., and Sumi, K., "Combined Lethal Effect of Temperature CO, CO_2 and O_2 of Simulated Fire Gases," *Fire and Flam.*, 4 (April 1973) pp. 132-140.

Tsuchiya, Y., and Sumi, K., "Evaluation of the Toxicity of Combustion Products," *Fire and Flam.*, 3 (Jan. 1972) pp. 46-50.

Yuill, C. H., "The Life Hazard of Bedding Fires," *Fire Technology*, 1 (Oct. 1970) pp. 312-323.

D-1.3 Smoke Test Methods.

Bartosic, A. J., and Rarig, F. J., "Evaluation of the XP2 Smoke Density Chamber," *Fire Test Methods — Restraint and Smoke* (1966) ASTM STP422, 1967.

Brenden, J. J., "Usefulness of a New Method for Smoke Yield from Species and Panel Products," *Forest Prod. J.*, 21 (1971) pp. 23-28.

Christian, W. J., and Waterman, T. E., "Ability of Small-Scale Tests to Predict Full-Scale Smoke Production," *Fire Technology*, 7, 4 (Nov. 1972) pp. 332-344.

Comeford, J. J., and Birky, M., "A Method for the Measurement of Smoke and HCL Evolution from Poly(vinyl-chloride)," *Fire Technology*, 8, 2 (May 1972) pp. 85-90.

Gardon, R., "An Instrument for the Direct Measurement of Intense Thermal Radiation," *Review of Scientific Instruments*, Vol. 24 (1953) pp. 366-370.

Gross, D.; Loftus, J. J.; and Robertson, A. F., "Method for Measuring Smoke from Burning Materials," *Fire Test Methods — Restraint and Smoke* (1966) ASTM STP422, 1967.

Lee, T. G., "Interlaboratory Evaluation of Smoke Density Chamber," *NBS Tech. Note 708* (Dec. 1971).

Lee, T. G., "The Smoke Density Chamber Method for Evaluating the Potential Smoke Generation of Materials," *NBS Tech. Note 757* (Jan. 1973).

Method of Test for Surface Flammability of Materials Using a Radiant Heat Energy Source, Designation E-162 Annual Book of ASTM Standards (1973).

NFPA 255-1984, *Standard Method of Test of Surface Burning Characteristics of Building Materials.*

Rasbash, D. J., "Smoke and Toxic Products Produced at Fires," *Trans. J. Plastics Inst.* (Jan. 1967) pp. 55-61.

Silversides, R. G., "Measurement and Control of Smoke in Building Fires," *Fire Test Methods — Restraint and Smoke* (1966) ASTM STP422, 1966.

Smith, E. E., "Measuring Rate of Heat, Smoke, and Toxic Gas Release," *Fire Technology*, 3, 3 (Aug. 1972) pp. 237-245.

ASTM Committee D-20, *Standard Test Method for Density of Smoke from the Burning or Decomposition of Plastics*, Annual Book of ASTM Standards, Designation D2843.

D-1.4 Smoke Behavior During Fires.

Bell, D., and Lieberman, P., "Smoke and Fire Propagation in Compartment Space," *Fire Technology*, 9, 2 (May 1973) pp. 91-100.

Carhart, H.; Hazlett, R. N.; Johnson, E.; and Stone, J. P., "The Transport of Hydrogen Chloride by Soot from Burning Polyvinylchloride," *Fire and Flam.*, 4 (Jan. 1973) pp. 42-51.

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Hinkley, P. L., "The Flow of Hot Gases Along an Enclosed Shopping Mall — A Tentative Theory," Joint Fire Res. Org., *Fire Research Note 807* (March 1970). See also *Fire Research Abstracts and Reviews*, 12, 3 (1970) p. 235.

"Movement of Smoke on Escape Routes in Buildings" (Proceedings of the Symposium held at Watford College of Technology) Joint Fire Res. Org., Her Majesty's Stationery Office, London (1971).

Shorter, G. W., "The St. Lawrence Burns," *NFPA Quarterly*, 53, 4 (April 1958) pp. 300-316.

D-1.5 Smoke Management During Fires.

"Explanatory Paper on Control of Smoke Movement in High Buildings," *National Building Code of Canada*, Nat. Res. Council, Canada, NRC, No. 11413.

Haggerty, J. R., "A New Look at Smoke Stop Partitions," *Fire Technology*, 6, 2 (May 1970) pp. 102-110.

McGuire, Tamura, and Wilson, "Factors in Controlling Smoke in High Buildings," ASHRAE Symposium, *Fire Hazards in Buildings* (Jan. 1970) pp. 8-13.

Shaw, C., and Tamura, G., "Basis for the Design of Smoke Shafts," *Fire Technology*, 9, 3 (Aug. 1973) pp. 209-222.

Shern, J. H., "Smokeproof Towers in Center Core Structures," *Fire Technology*, 2, 4 (Nov. 1966) pp. 303-307.

Shorter, G. W., and Wilson, A. G., "Fire and High Buildings," *Fire Technology*, 6, 4 (Nov. 1970) pp. 292-304.

D-1.6 Chemical Analysis of Fire Gases.

DiPietro, J., and Stepniczka, H., "A Study of Smoke Density and Oxygen Index of Polystyrene ABS and Polyester Systems," *Fire and Flam.*, 2 (Jan. 1971) pp. 36-53.

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Woodley, Ann I., and Woolley, W. D., *The Thermal Decomposition Products of Phenol-Formaldehyde Laminates*.

D-1.7 Smoke Production Measurements.

Gaskill and Veith, "Smoke Opacity from Certain Woods and Plastics," *Fire Technology*, 4, 3 (1968) pp. 185-195.

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3. In the space identified as "Proposal" include the wording you propose as new or revised text, or indicate if you wish to delete text.
4. In the space titled "Statement of Problem and Substantiation for Proposal" state the problem which will be resolved by your recommendation and give the specific reason for your proposal including copies of tests, research papers, fire experience, etc. If a statement is more than 200 words in length, the technical committee is authorized to abstract it for the Technical Committee Report.
5. Check the box indicating whether or not this proposal is original material, and if it is not, indicate source.
6. If supplementary material (photographs, diagrams, reports, etc.) is included, you may be required to submit sufficient copies for all members and alternates of the technical committee.

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(c) a statement of the problem and substantiation for the proposal, and

(d) proposed text of proposal, including the wording to be added, revised (and how revised), or deleted.