NFPA 258

Standard Research Test Method for Determining Smoke Generation of Solid Materials

1997 Edition

NFPA®

National Fire Protection Association, 1 Batterymarch Park, PO Box 9101, Quincy, MA 02269-9101
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NFPA 258

Standard Research Test Method for

Determining Smoke Generation of Solid Materials

1997 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 19–22, 1997, in Los Angeles, CA. It was issued by the Standards Council on July 24, 1997, with an effective date of August 15, 1997, and supersedes all previous editions.

This edition of NFPA 258 was approved as an American National Standard on August 15, 1997.

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 major role of combustion products 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 a hazard to life have, to date, precluded their exact technical assessment. A test method, such as the one described 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 this test method for rough analysis of the smoke production during an actual fire is informative in demonstrating 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. It also provides a means for reporting the rate of smoke production and the time at which specific smoke levels are reached under the test conditions applied.

The concept of specific optical density, while outdated in terms of photometric practice, was first introduced for measuring smoke as part of the smoke density chamber test method.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 tentatively adopted by the NFPA as a standard in 1974. A revised edition was adopted as a standard in 1976 and reconfirmed at the NFPA 1981 and 1986 Fall Meetings. The 1989 edition reflected a minor revision to the scope statements of the standard.

The 1994 edition was a reconfirmation of the 1989 edition with minor editorial changes and updating of the references within the document.

The 1997 edition is also a reconfirmation of the earlier edition. The committee recognizes that this standard is used by many in industries and governmental agencies for determination of smoke generation from specific solid materials. The original intent during the development of this standard was that the standard was to be used for a research and development tool. The committee is currently developing a proposed standard NFPA 270, *Determination of Specific Official Density of Smoke,* which can be used for regulatory purposes. This proposed standard will replace the current edition of NFPA 258.

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NOTICE: An asterisk (*) following the number or letter designating a paragraph indicates that explanatory material on the paragraph can be found in Appendix A.

Information on referenced publications can be found in Appendix E.

Chapter 1 General

1-1 Scope.

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

1-1.2 Measurement is made of the attenuation of a light beam by the suspended solid or liquid particles, that is, smoke, that 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* Test results shall be expressed in terms of specific optical density, which is a dimensionless value derived from the measured light transmission and geometric measurements of the chamber and the specimen.

1-1.4 This test shall be used only as a research and development tool. It shall not be used as a basis for determining ratings for building codes 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 it 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 test method shall provide a means for comparing the specific optical density of the smoke, which is generated by materials and assemblies, in the form and thickness tested and under the specified exposure conditions.

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

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

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

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

1-3 Summary of Method.

1-3.1 This method for measuring the smoke that is generated by materials employs an electrically heated, radiant energy source, which is mounted within an insulated, ceramic tube. This radiant energy source is positioned to produce an irradiance level of 2.2 Btu/sec·ft^2 (2.5 W/cm^2) that is averaged over the central $1^1/_2$-in. (38.1-mm) diameter area of a vertically mounted specimen facing the radiant heater. The nominal 3-in. × 3-in. (76.2-mm × 76.2-mm) specimen shall be mounted within a holder that exposes an area that measures $2^9/_{16}$ in. × $2^9/_{16}$ in. (65.1 mm × 65.1 mm). The holder can accommodate specimens that are 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 shall be used to apply a row of equidistant, premixed, that is, 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, shall constitute the flaming combustion exposure.

1-3.3 The test specimens shall be 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 shall be continued 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 B-2, shall be followed.

1-3.5* The light transmittance measurements shall be used to express the smoke, which is generated by the test materials, in terms of the specific optical density during the time necessary to reach the maximum value.

Chapter 2 Test Apparatus

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

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. × 24 in. × 36. in. ± $^1/_8$ in. (914 mm × 610 mm × 914 mm ± 3 mm) for width, depth, and height, respectively.

2-2.2* The interior surfaces shall consist of porcelain-enameled metal or equivalent coated metal that is 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. (approximately 0.025 mm) or less in thickness] safety-blowout panel that is 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.

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

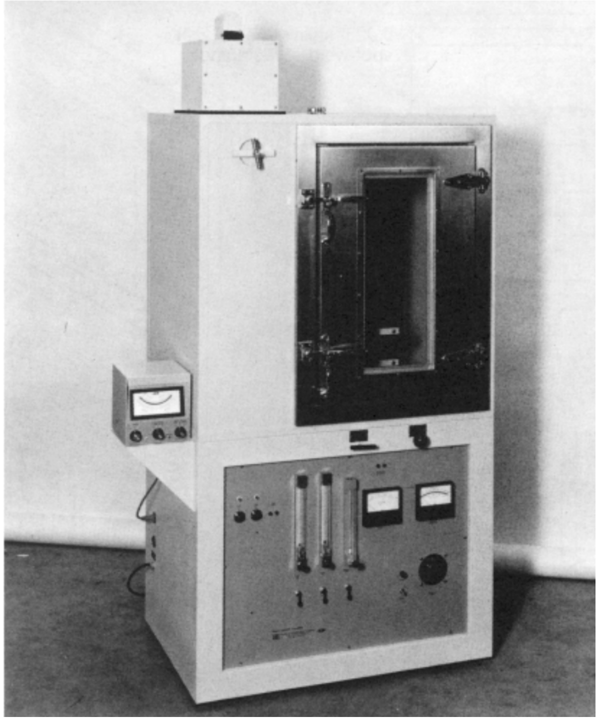


Figure 2-1(a) Smoke density chamber.

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 centerline, equidistant between the front and back of the chamber, with the opening facing toward and approximately 12 in. (305 mm) from the right wall.

2-3.3 The centerline of the furnace shall be approximately $7^3/_4$ in. (195 mm) above the chamber floor.

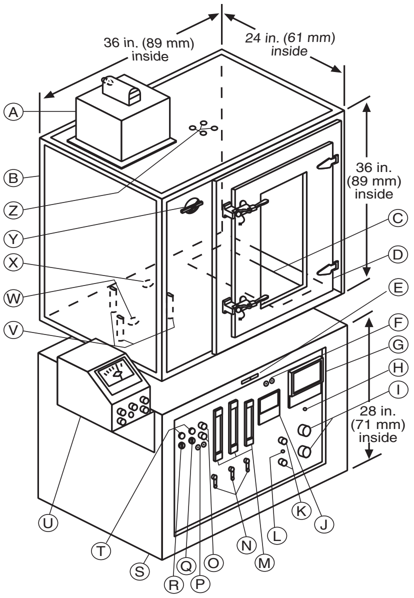
2-3.4 Furnace Control System.

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.

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

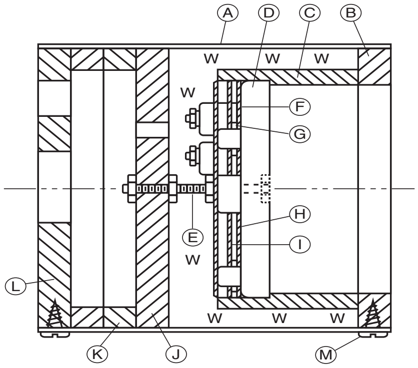
2-4 Specimen Holder. •Specimen holders shall conform in shape and dimension to that shown in Figure 2-4, and they shall be fabricated to expose a 2 $^9/_{16}$-in. × 2 $^9/_{16}$-in. (65.1-mm × 65.1-mm) specimen area. The spring and rods for retaining the specimen within the holders shall be as shown in Figure 2-4.

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



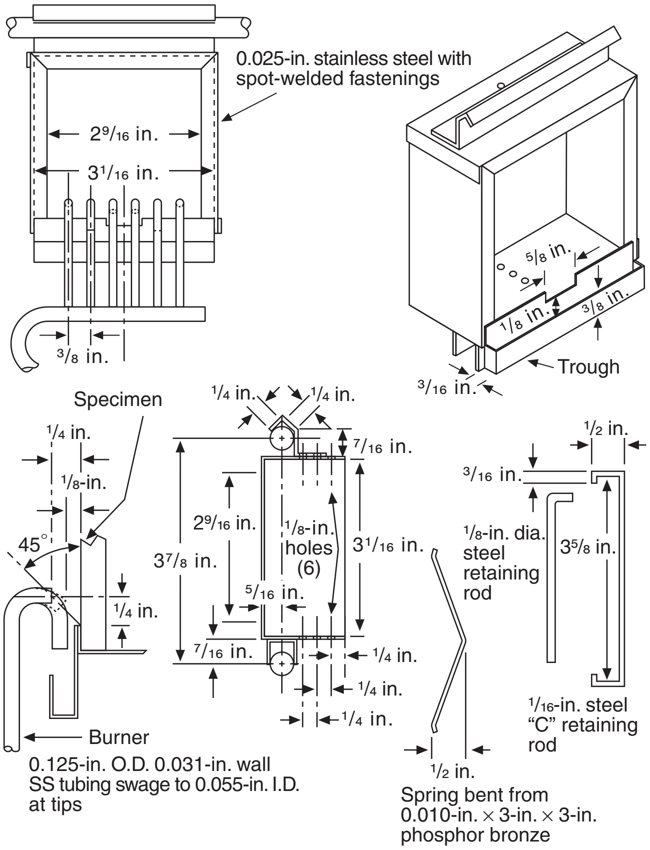
A — Phototube enclosure
B — Chamber
C — Blowout panel
D — Hinged door with window
E — Exhaust vent control
F — Radiometer output jack
G — Temperature (wall) indicator
H — Temperature indicator switch
I — Autotransformers
J — Voltmeter (furnace)
K — Fuse holders
L — Furnace heater switch
M — Gas and air flowmeters
N — Gas and 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

Figure 2-1(b) Smoke density chamber assembly.



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.



For SI units: 1 in. = 25.4 mm.

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

2-6 Photometric System.

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

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

(a) The *light source* shall be an incandescent lamp, which is operated at a fixed voltage in a circuit that is powered by a voltage-regulating transformer. The light source shall be mounted in a sealed and light-tight box, which is 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 10A. A sealed box, which is located directly opposite of 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.

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

2-7.3 The radiometer shall have a stainless steel, reflective heat shield with a $1^{1}/_{2}$-in. (38.1-mm) aperture on the front and a finned cooler, which is supplied with compressed air, mounted on the rear to maintain a constant body temperature of 200°F ± 5°F (93°C ± 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 that is capable of measurement over a range of five decades or more. *(See B-1.4.)*

2-10 Manometer for Chamber Pressure Measurements.

2-10.1 A simple water manometer with a range of up to 6 in. (152 mm) of water shall be provided to monitor chamber pressure and leakage. *(See B-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 B-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 $^{1}/_{4}$ in. ± $^{1}/_{16}$ in. (6.4 mm ± 1.6 mm) above the holder edge and $^{1}/_{4}$ in. ± $^{1}/_{16}$ in. (6.4 mm ± 1.6 mm) away from the specimen surface.

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

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

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

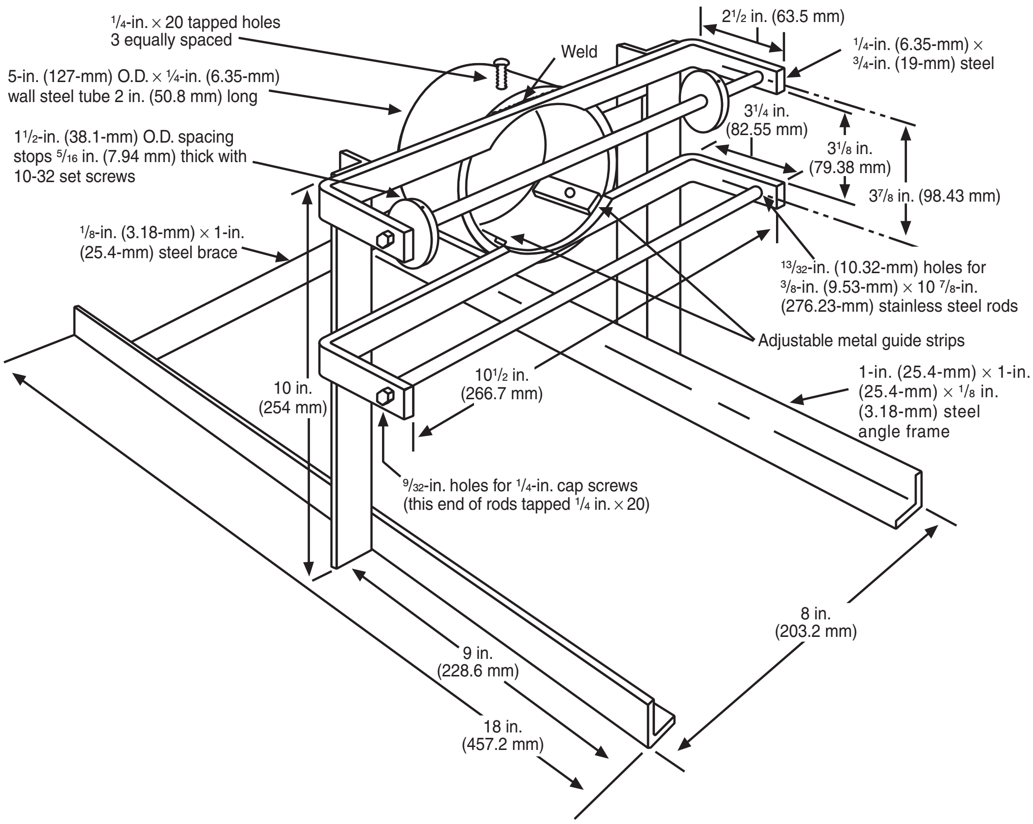


Figure 2-5 Furnace support.

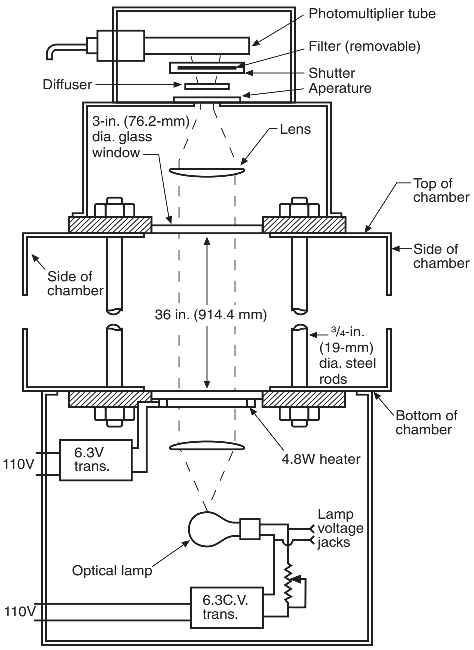


Figure 2-6.2(a) Photometer details.

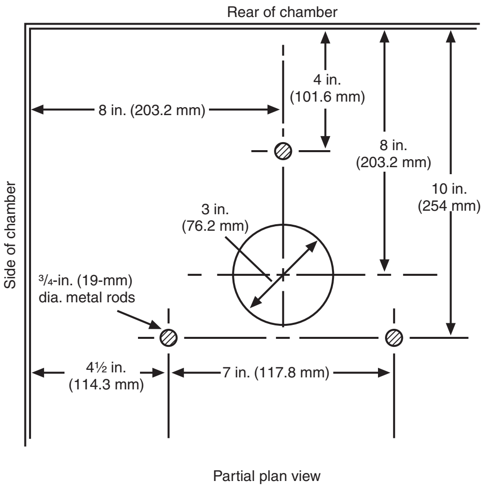


Figure 2-6.2(b) Photometer location.

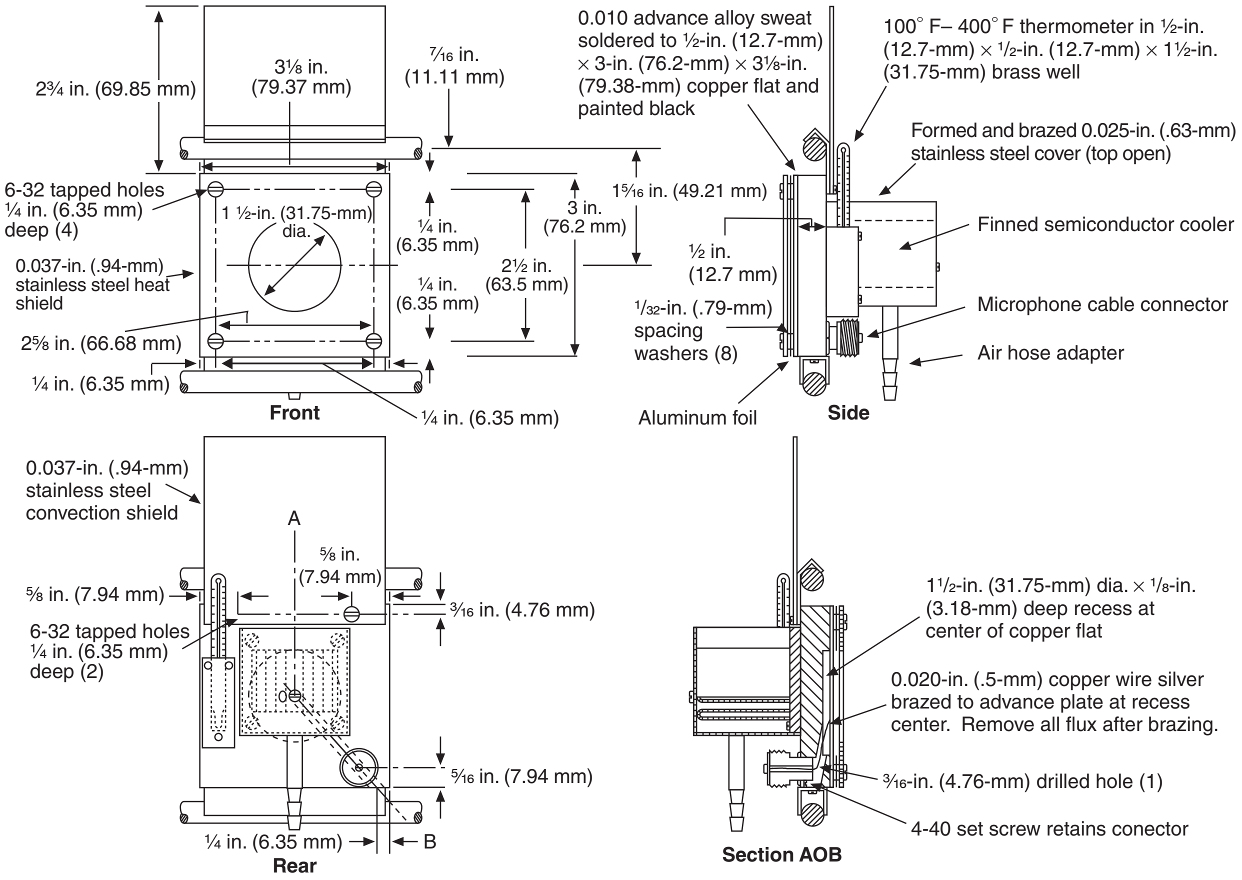


Figure 2-7.2 Radiometer detail.

Chapter 3 Test Specimens

3-1 Specimen Description.

3-1.1 Size.

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

3-1.1.2 Specimens that are 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 shall be tested.

3-1.1.3 Multilayer materials that are greater than 1 in. (25.4 mm) thick and that consist 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.

Exception: Flat sections of the same thickness and composition shall be permitted to 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 the test.

3-1.3.3* Where 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.

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) Using recommended or practical application techniques and coverage rates, liquid films, for example, paints and adhesives, which are intended for application to combustible base materials, shall be applied to the smooth face of 1/4-in. (6.4-mm) thick tempered hardboard with a nominal density of 50 lb/ft^3 to 60 lb/ft^3 (0.8 g/cm^3 to 0.97 g/cm^3). Tests also shall be conducted on the hardboard substrate alone, and these values shall be recorded as supplemental to the measured values for the composite specimen.

(c) Using recommended or practical application techniques and coverage rates, liquid films, for example, paints and adhesives, which are intended for application to noncombustible substrate materials, shall be applied to the smooth face of $^1/_4$-in. (6.4-mm) thick asbestos-cement board with a nominal density of 120 lb/ft^3 (1.9 g/cm^3).

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

3-3 Specimen Conditioning. Specimens shall be predried for 24 hours at 140°F ± 5°F (60°C ± 3°C) and then conditioned to equilibrium, that is, constant weight, with an ambient temperature of 73°F ± 5°F (23°C ± 3°C) and a relative humidity of 50 percent ± 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 in. ± 0.0005 in. (approximately 0.04 mm) thick].

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 that minimizes loss 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.

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 a spring and retaining rod. A modified, C-shape retaining rod shall be used with specimens that are from $^5/_8$ in. to 1 in. (15.9 mm 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. For example, if the area is reduced to 1$^1/_2$ in. wide × 3 in. high (38.1 mm wide × 76.2 mm high) and is centrally located, the appropriate area shall be used in calculating *Ds. (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°F ± 5°F (23°C ± 3°C) and relative humidity of 50 percent ± 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.

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

4-2.2* The exposed surfaces of the glass windows that separate the photodetector and the light source housing from the interior of the chamber shall be cleaned before each test.

4-3 Warm-up of Furnace.

4-3.1 During the warm-up period all electric systems, for example, furnace, light source, and photometer readout, shall be on; the exhaust vent and chamber door shall be closed; and the inlet vent shall be 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°F ± 4°F (35°C ± 2°C), the chamber shall be ready for furnace calibration or testing.

4-3.3* According to test experience, the furnace output irradiance shall be calibrated, without the burner in place, at periodic intervals.

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

Exception: Where displaced to the side by the specimen holder during a test or 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 ±$^1/_{16}$ in. (± 1.6 mm) of 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 the inlet vent opened, the compressed air supply to the radiometer cooler shall be adjusted to maintain its body temperature at 200°F ± 5°F (93°C ± 3°C).

4-3.7 The autotransformer setting shall be adjusted to obtain the radiometer's calibrated millivolt output, which corresponds to a steady-state irradiance of 2.2 Btu/sec·ft^2 ± 0.04 Btu/sec·ft^2 (2.5 W/cm^2 ± 0.05 W/cm^2) that is averaged over the central 1$^1/_2$-in. (38.1-mm) diameter area.

4-3.8 The recorder or meter, which is 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 or recorder zero, or both, shall be adjusted.

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

4-3.11 The "dark current," that is, 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. The burner distance, relative to the "blank" specimen, shall be checked before fuel adjustment and ignition.

4-5 Procedures. Before positioning the test specimen, the chamber shall be flushed for approximately 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 then shall be closed.

4-5.2 The loaded specimen holder shall be placed on the bar support and shall be 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 closed quickly and the timer or recorder chart drive, or both, shall be started simultaneously. 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 multirange recorder or at sufficient time intervals with a multirange meter readout. The necessary full-scale range changes in decade steps shall be observed and noted.

4-5.5 The increase in chamber pressure shall be observed with the manometer, which is described in Section 2-10. A regulator *(see B-1.8)* shall be used to maintain the pressure in the range of 4 in. ± 2 in. (100 mm ± 50 mm) of water during most of the test. If negative pressure develops after 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 that are pertinent to the burning and smoke-generating properties of the material under testing 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 to extend the measuring range. If extraneous light can reflect into the photometer during removal of the filter, the high voltage shall be turned off or the scale shall be adjusted to minimize sensitivity. The filter shall be replaced before exhausting the smoke from the chamber.

4-5.9 *The burner on flaming exposures shall be extinguished, and exhausting of the chamber shall be initiated within 1 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. This transmittance value shall be recorded as the T_c, "the clear beam" reading, which shall be used to correct for deposits on the photometer windows.

Chapter 5 Calculations

5-1 Specific Optical Density. 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, shall be calculated 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 that is 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 generally are less than 1 percent and shall be permitted to be disregarded.

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

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

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

5-3 Light Transmittance. 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 the following equation:

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

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

Chapter 6 Report

6-1 Documentation. The report *(see Appendix C)* shall include the following items:

(a) A complete description of the specimen tested, including type, manufacturer, shape, thickness, weight or density, coloring, and other appropriate dimensions

(b) A complete description of the test specimens, including substrate or core, special preparation, and mounting

(c) The test specimen conditioning procedure

(d) The number of specimens tested

(e) The test conditions, such as type of exposures, type of holder used, and exposure period

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

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

(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.)*

(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.

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

Appendix A Explanatory Material

This appendix is not part of the requirements of this NFPA document but is included for informational purposes only.

A-1-1.3 A commentary describing the significance of specific optical density and appropriate considerations for application of test results is included in Appendix D.

A-1-2.1 Attempts are now underway to relate the results of this test to the measurement of smoke that is generated under large-scale test conditions. Other test methods for measuring smoke have been reviewed and summarized in C. M. Yuill et al., "The Control of Smoke in Building Fires — A State-of-the-Art Review," 1971.

A-1-3.5 Additional parameters, such as the maximum rate of smoke accumulation, the time to a fixed optical density level, or a smoke obscuration index, might be more appropriate in particular situations.

A-2-1 A more detailed description of the suggested apparatus is given in B-1.

A-2-2.2 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 $^3/_{16}$ in. (4.76 mm), have been found suitable.

A-2-3.4.2 Where line voltage fluctuations are present, a constant-voltage transformer might be needed to maintain the prescribed irradiance level.

A-2-7.1 The operation of a circular foil-type radiometer is described in R. Gardon, "An Instrument for the Direct Measurement of Intense Thermal Radiation," 1953.

A-3-1.3.1 Substrate or core materials for the test specimens should be the same as those for the intended application. Where a material or assembly might be exposed to a potential fire on either side, both sides should be tested.

A-3-1.3.3 Finish materials, including sheet laminates, tiles, fabrics, other materials that are secured to a substrate material with adhesive, and composite materials not attached to a substrate can be subject to delamination, cracking, peeling, or other separations affecting their smoke generation. To evaluate these effects, supplementary tests, which are performed on a scored, that is, slit, exposed surface or on interior layers or surfaces, might be necessary.

A-3-4.4 Problems that are associated with interpretation of experimental results when unburned molten drips occur are discussed in Appendix D.

A-4-2.1 Charred residues on the specimen holder and horizontal rods should be removed to avoid contamination. An ammoniated spray detergent and soft scouring pads have been found effective in removing the residues.

A-4-2.2 Generally, ethyl alcohol has been found to be effective for cleaning the surfaces of the glass windows.

A-4-3.2 To increase the chamber wall's surface temperature to the stated level under adverse conditions, an auxiliary heater can be used. Conversely, to decrease this temperature, the exhaust blower can be used to introduce cooler air from the laboratory.

A-4-3.3 Periodic intervals have been shown by test experience normally to consist of two calibrations per test day.

A-4-5.9 In some cases, the transmittance can somewhat increase and subsequently decrease to the ultimate minimum transmittance.

A-6-1(g) Although not specifically required as part of the method, products of combustion can be drawn from the chamber at various times during the test for analysis. The physical properties of the smoke can be investigated by electrostatic or impact collection and various methods of particle analysis. The presence and concentrations of various toxic and irritating gaseous products can be determined by using colorimetric gas detector tubes, gas chromatography methods, ion-selective electrodes, or other techniques.

A-6-1(i) Sufficient test results should result in the development of a smooth curve of *Ds* versus time.

Appendix B Apparatus Construction and Calibration

This appendix is not a part of the requirements of this NFPA document but is included for informational purposes only.

B-1 Construction Details.

B-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), which is mounted vertically in a horizontal ceramic tube. The tube has a 3-in. (76.2-mm) inside diameter × $3^3/_8$-in. (85.7-mm) outside diameter and is $1^5/_8$ in. (41.3 mm) long. The tube is bored out at one end to have a $3^1/_{32}$-in. (77.0-mm) inside diameter and to have a depth of $^5/_8$ 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 $^3/_8$-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 the front of the $^3/_8$-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 that are adjacent to the heating element assembly should be packed with glass wool. The furnace assembly is housed in a 4-in. (102-mm) outside diameter, 0.083-in. (2.1-mm) wall, $4^1/_8$-in. (105-mm) long stainless steel tube. Two additional $^3/_8$-in. (9.5-mm) asbestos board spacing rings and a rear cover of $^3/_8$-in. (9.5-mm) asbestos board complete the furnace. The furnace should be located centrally along the long axis of the chamber with the opening facing toward and approximately 12 in. (305 mm) from the right wall. The centerline of the furnace should be about $7^3/_4$ in. (195 mm) above the chamber floor.

B-1.2 Specimen Holder. *(See Section 2-4.)* The specimen holder should conform to Figure 2-4 in shape and dimension and should be fabricated by bending and brazing (or spot welding) 0.025-in. (0.6-mm) thick stainless steel to provide a $1^1/_2$-in. (38.1-mm) depth and to expose a $2^9/_{16}$-in. × $2^9/_{16}$-in. (65.1-mm × 65.1-mm) specimen area. As described in Section 2-5, the holder should have top and bottom guides to permit accurate centering of the exposed specimen area in relation to the furnace opening. A 3-in. × 3-in. (76.2-mm × 76.2-mm) sheet of $^1/_2$-in. (12.7-mm) asbestos millboard, having a nominal density of 50 lb/ft^3 ± 10 lb/ft^3 (0.85 g/cm^3 ± 0.17 g/cm^3), should be used to back the specimen. A spring bent from a 0.010-in. (approximately 0.25-mm) thick phosphor bronze sheet should be used with a steel retaining rod to hold the specimen and millboard backing securely in position during testing.

B-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) outside diameter, $^1/_4$-in. (6.4-mm) wall, 2-in. (50.8-mm) long, horizontally oriented steel tube to support the radiant heat furnace, which is described in Section 2-3. This support tube should have provisions to align the furnace opening accurately so that it is $1^1/_2$ in. ± $^1/_{16}$ in. (38.1 mm ± 1.6 mm) away from, parallel to, and centered horizontally and vertically to within ± $^1/_{16}$ in. (1.6 mm) of the exposed specimen area. Three tapped holes with screws that are 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 the tube, are to provide for adequate alignment.

The framework should have two $^3/_8$-in. (9.5-mm) diameter transverse rods of stainless steel to accept the guides of the specimen holder as described in B-1.2. The rods should support the holder so that the exposed specimen area is parallel to the furnace opening. Spacing stops should be mounted at both ends of each rod to permit quick and accurate lateral positioning of the specimen holder.

B-1.4 Photometric System. *(See Section 2-6.)* The photometric system should consist of a tungsten-filament light source (Type 1630 6.5 volt lamp, maintained at 4 V ± 0.2 V) and a photodetector with an S-4 spectral sensitivity response. The photometer should be oriented vertically to reduce measurement variations, which are brought about by stratification of the smoke that is generated by the specimens being tested. This system is shown in Figures 2-6.2(a) and (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 should have a path length of 36 in. ± $^1/_8$ in. (914 mm ± 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 should 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 B-2.1.1.)*

The two optical platforms and their housings should be kept in alignment with three metal rods, $^1/_2$ in. (12.7 mm) in diameter and fastened securely into $^5/_{16}$-in. (7.9-mm) thick, externally mounted, top and bottom plates, and they should be symmetrically arranged about the collimated light beam.

B-1.5 Radiometer. *(See Section 2-7.)* The body temperature of the radiometer should be monitored with a 100°F to 220°F (38°C to 100°C) thermometer in a $^1/_2$-in. × $^1/_2$-in. × $1^1/_2$-in. (12.7-mm × 12.7-mm × 38.1-mm) brass well, which is drilled to accept the thermometer with a close fit. Silicone grease can 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 should be calibrated calorimetrically in accordance with the procedure summarized in B-2.2.

B-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 $^1/_4$-in. (6.4-mm) thick, polystyrene foam disk cover and epoxy cement.

B-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 an $^1/_8$-in. (3.2-mm) outside diameter, 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 a $^1/_4$-in. (6.4-mm) outside diameter, 0.035-in. (0.9-mm) wall, stainless steel tubing. The other end is attached to a fitting in the chamber floor.

B-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.

B-2 Calibration of Test Equipment.

B-2.1 Photometric System.

B-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 that are measured by the photometer should be within ± 3 percent of the calibrated values.

B-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.

B-2.1.3 The optical density of a supplementary filter that is used to extend the measuring range of the photometer should have an accuracy of ± 3 percent.

B-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°F ± 5°F (93°C ± 3°C) with controlled airflow through the rear-mounted cooler and by 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 [$1^1/_2$-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) and corresponding to an irradiance level of 2.2 Btu/sec·ft^2 ± 0.04 Btu/sec·ft^2 (2.5 W/cm^2 ± 0.05 W/cm^2) is used to establish the furnace control settings as discussed in 4-3.2.

B-2.3 Chamber Pressure Manometer — Leak Rate Test. For purposes of standardization, a leakage rate test should be periodically conducted by using the manometer and tubing, which is 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.

B-2.4 Standard Smoke-Generating Materials. For checking operational and procedural details of the equipment and the test method described in this standard, two standard materials can be used—SRM 1006, Alpha Cellulose (Smoke Density), NIST, and SRM 1007, Plastic (Smoke Density), NIST. Under nonflaming conditions a single layer of alpha-cellulose, that is, 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 that is outlined in this standard.

Appendix C Suggested Report Form — Smoke Density Chamber

This appendix is not a part of the requirements of this NFPA document but is included for informational purposes only.

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 ______ in. 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

Minimum trans ______ % at ______ min
Max. specific optical density, D_m = ______
Clear beam reading = ______ %;
Equiv. D_c ______
D_m (corr.) = $D_m - D_c$ = ______

Remarks

______

Appendix D Commentary

This appendix is not a part of the requirements of this NFPA document but is included for informational purposes only.

D-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, numerous publications have reported on its application and on studies of the correlation of results of interlaboratory tests through its use. [2–8]

D-1.1 The method is somewhat like the box-type test, which was 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 that is produced.

Advantages provided by use of this test method include the following:

(a) The smoke collection chamber essentially is sealed so all smoke that is produced during a test is retained.

(b) 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.

(c) A vertical photometer is used as a means for avoiding measurement errors resulting from smoke stratification.

(d) Provisions are included for reporting the result of smoke measurements in terms of specific optical density, which is a measurement of the amount of smoke that is produced and, therefore, is useful for comparing one composition of a material against another.

D-1.2 Measurements that are made with the test relate to light transmission through smoke.

D-2 Features of Test Method.

D-2.1 Two exposure conditions can be simulated by the test:

(a) Radiant heating in the absence of ignition

(b) An open-flame 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 2.2 Btu/sec·ft^2 (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.

D-2.1.1 From a scientific viewpoint, having constant irradiance over all portions of the specimen would be desirable. From a practical point of view, this condition is 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, which is specified in the test method, is that measured by the radiometer that is described in the standard, an instrument sensitive only to the $1^1/_2$-in. (38.1-mm) diameter central area of the specimen holder.

D-2.2 Figure D-1 shows the result of one survey of irradiance across the specimen diagonal. This result suggests that the overall average effective flux level during nonflaming pyrolysis is probably about 2.0 Btu/sec·ft^2 (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.

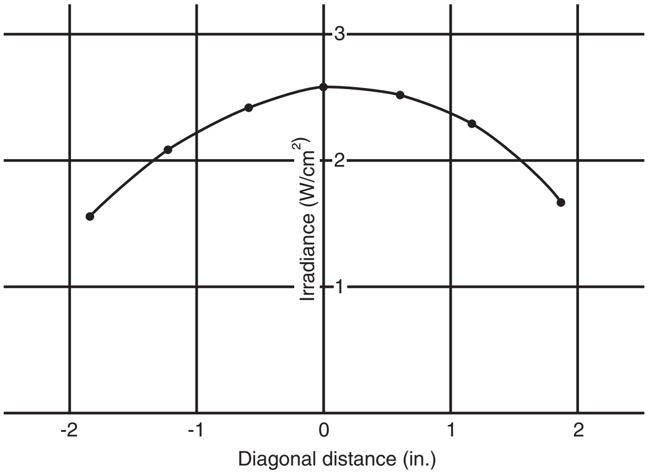


Figure D-1 Diagonal survey of irradiance at specimen during operation at nominal 2.2 Btu/sec·ft^2(2.5 W/cm^2).

D-2.2.1 The primary measurement, which is made during the conduct of the test, is of the amount of light transmitted as a fraction or percentage of the initial light that is transmitted by the optical system. The minimum percent of the light transmitted value is, in turn, used to calculate the maximum specific optical density, D_m, value, in accordance with Chapter 5. There is some advantage to using specific optical density as a value by which to evaluate results as compared to using percent of light transmittance.

D-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:

$$T = T_o e - \sigma^L$$

where:

T = % flux transmittance

T_o = 100, the initial transmitted flux

σ = attenuation coefficient

L = length of the optional path

e = 2.7183

D-2.2.3 While the smoke that is 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 the purposes intended, optical density can be considered to be proportional roughly to the smoke particulates that are produced. The measurement unit, specific optical density, *Ds,* has been introduced to provide a conveniently factored rating scale as follows:

$$D_s = (V/AL)\ d = (V/AL) \log (100/T)$$

where $(V/AL) = 132$.

Previous draft versions of this test method have proposed that, in the situation where the smoke that is produced exceeded the measurement capability of the apparatus, or if only small specimens were available, specimens of 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.

D-2.2.3.1 Certain other test methods report smoke simply in terms of light transmission. The problem with such a procedure is that a person who is unfamiliar with the characteristics of smoke aerosols might assume that the percent of light transmittance is a reciprocal, linear function of the quantity of smoke produced, thus concluding that as the quantity of smoke produced is doubled, the percent light transmittance is cut in half. This supposition is not true.

D-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 it permits reporting smoke development in terms that recognize the area of the involved specimen, the volume of the box, and the optical path length of the photometer. Specific optical density is without dimension. Its value should, however, be recognized as relating to the specimen only in the tested thickness. 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. [11] At the present time, techniques for using this theoretical approach have not been developed to a practical stage because of the following influences:

(a) Variations in types of fire exposure

(b) Rate of involvement of a material in a fire

(c) Ventilation characteristics of the compartment

(d) Degree of stratification of the accumulated smoke

These are, in most instances, undetermined variables that greatly influence light transmission through smoke resulting from a fire.

D-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 outlined in the following paragraphs.

D-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.

D-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 the following two effects:

(a) Close spacing causing more smoke to enter the furnace and become consumed there

(b) Reduced air circulation moving past the specimen, which inhibited open-flame combustion

As a result, the separation, which is called for in B-1.3, of $1^1/_2$ in. ± $^1/_{16}$ in. (38.1 mm ± 1.6 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 in. ± $^1/_{32}$ in. (76.2 mm ± 0.8 mm) between the heater face and the specimen surface.

D-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 in which this could occur introduced an undesirable variability in the measurements.

D-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 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 to melt and drip in varying degrees 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 the performance that might be expected from the same materials in another fire exposure. Thus, there does not seem to be any reason to ban thermoplastic materials that melt or drip into the trough from the test.

D-4 Precision.

D-4.1 In any method, one of the important considerations is the degree to which a method, 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.

This fact was recognized in planning the large interlaboratory study of the precision of the measurement method. In spite of this planning, some of the experimental variability that was observed was related undoubtedly 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, which resulted from this cause, requirements for weighing specimens have now been included as a part of the test procedure.

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

D-4.2.1 When studying the results that are reported by the various laboratories participating in the round-robin study, it was realized that the test method draft that was 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.

D-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 factor be applied to the measured D_m (corr.). The reporting of D_m as a preferred measurement result is based on the following fact:

The remaining deposit, which follows a test, represents a part of the smoke produced. Thus, it seems irrational to subtract this value 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.

D-5.1 Experience has shown that the determination of the value of T, which is used eventually to calculate D_m (corr.), is subject to variations in operator technique during the chamber venting procedure.

D-5.2 The introduction of the correction factor, while not in itself a significant technical problem, suggests a technical sophistication that simply is not justified on the basis of the 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).

D-6 Limitations on Application of Smoke Measurement Data.

D-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) The fact that most materials or products, when burning, release large quantities of smoke, and there are only limited ways of reducing smoke production

The first problem still exists, and 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 should be recognized as based only on the fire exposure conditions applied, and, in fact, the test method develops different rankings depending on whether a ranking is based on the nonflaming exposure or the flaming exposure. All of the parameters that affect fire behavior will influence the amount of smoke that is 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.

The third problem also 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, 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 would have to be maintained continually.

D-6.2 It is important to remember that, for any given thermal exposure condition, the smoke that is produced when a fire occurs is related to the thickness and density of the material involved. The importance of specimen thickness is illustrated in Figure D-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.

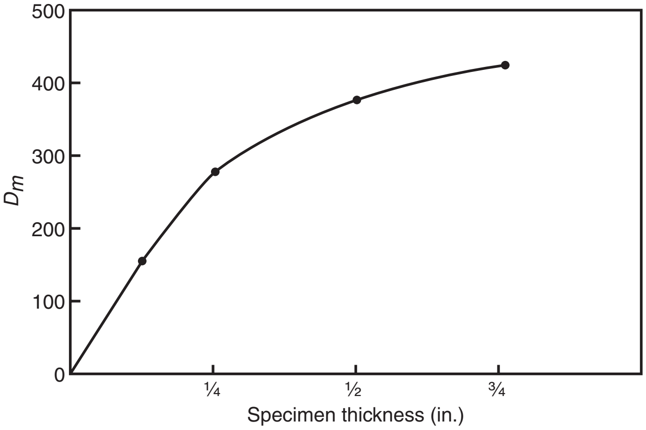


Figure D-2 D_m **for spruce as a function of specimen thickness under nonflaming conditions.**

D-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 a time at which specific smoke levels are reached under the applied test conditions.

Appendix E Referenced Publications

E-1 The following documents or portions thereof are referenced within this standard for informational purposes only and are thus not considered part of the requirements of this standard. The edition indicated here for each reference is the current edition as of the date of the NFPA issuance of this standard.