ASTM

Designation: E 662 – 97

An American National Standard

Standard Test Method for
Specific Optical Density of Smoke Generated by Solid Materials[1]

This standard is issued under the fixed designation E 662; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This fire-test-response standard covers determination of the specific optical density of smoke generated by solid materials and assemblies mounted in the vertical position in thicknesses up to and including 1 in. (25.4 mm).

1.2 Measurement is made of the attenuation of a light beam by smoke (suspended solid or liquid particles) accumulating within a closed chamber due to nonflaming pyrolytic decomposition and flaming combustion.

1.3 Results are expressed in terms of specific optical density which is derived from a geometrical factor and the measured optical density, a measurement characteristic of the concentration of smoke.

1.4 This test method is intended for use in research and development and not as a basis for ratings for regulatory purposes.

1.5 *This standard should be used to measure and describe the response of materials, products, or assemblies to heat and flame under controlled conditions and should not be used to describe or appraise the fire-hazard or fire-risk of materials, products, of assemblies under actual fire conditions. However, results of the test may be used as elements of a firehazard assessment or a fire-risk assessment which takes into account all of the factors which are pertinent to an assessment of the fire hazard or fire risk of a particular end use.*

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.7 The values stated in inch-pound units are to be regarded as standard. Values stated in parentheses are for information only.

2. Referenced Documents

2.1 *ASTM Standards:*
D 2843 Test Method for Density of Smoke from the Burn-

ing or Decomposition of Plastics[2]
E 176 Terminology of Fire Standards[3]

3. Terminology

3.1 *Definitions*—For definitions of terms found in this test method refer to Terminology E 176.

4. Summary of Test Method

4.1 This test method 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/s·ft^2(2.5 W/cm^2) averaged over the central 1.5-in. (38.1-mm) diameter area of a vertically mounted specimen facing the radiant heater. The nominal 3 by 3-in. (76.2 by 76.2-mm) specimen is mounted within a holder which exposes an area measuring 2⁹⁄₁₆ by 2⁹⁄₁₆ in. (65.1 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.

4.2 For the flaming condition, a six-tube burner is used to apply a row of equidistant 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.

4.3 The test specimens are exposed to the flaming and nonflaming conditions within a closed chamber. A photometric system with a vertical light path is used to measure the varying light transmission as smoke accumulates. The light transmittance measurements are used to calculate specific optical density of the smoke generated during the time period to reach the maximum value.[4]

5. Significance and Use

5.1 This test method provides a means for determining the specific optical density of the smoke generated by specimens of materials and assemblies under the specified exposure conditions. Values determined by this test are specific to the

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[1] This test method is under the jurisdiction of ASTM Committee E-5 on Fire Standards and is the direct responsibility of Subcommittee E05.21 on Smoke and Combustion Products.

Current edition approved Sept. 10, 1997. Published April 1998. Originally published as E 662 – 79. Last previous edition E 662 – 95.

[2] *Annual Book of ASTM Standards*, Vol 08.02.

[3] *Annual Book of ASTM Standards*, Vol 04.07.

[4] Additional parameters, such as the maximum rate of smoke accumulation, time to a fixed optical density level, or a smoke obscuration index may provide useful information. See Appendix X1.

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specimen or assembly in the form and thickness tested and are not to be considered inherent fundamental properties of the material tested. Thus, closely repeatable or reproducible experimental results should not be expected from tests of a given material when specimen thickness, density, or other variables are involved.

5.2 The photometric scale used to measure smoke by this test method is similar to the optical density scale for human vision. However, physiological aspects associated with vision are not measured by this test method. Correlation with measurements by other test methods has not been established.[5]

5.3 At the present time no basis is provided for predicting the density of smoke that may be generated by the materials upon exposure to heat and flame under other fire conditions.

5.4 The test method is of a complex nature and the data obtained are sensitive to variations which in other test methods might be considered to be insignificant (see Section 6). A precision statement based on the results of a roundrobin test by a prior draft version of this test method is given in 14.1

5.5 In this procedure, the specimens are subjected to one or more specific sets of laboratory test conditions. If different test conditions are substituted or the end-use conditions are changed, it may not be possible by or from this test to predict changes in the fire-test-response characteristics measured. Therefore, the results are valid only for the fire-test-exposure conditions described in this procedure.

6. Limitations

6.1 If during the test of one or more of the three replicate samples there occurs such unusual behavior as (*1*) the specimen falling out of the holder, (*2*) melted material overflowing the sample holder trough, (*3*) self-ignition in the pyrolysis mode, (*4*) extinguishment of the flame tiplets (even for a short period of time), or (*5*) a specimen being displaced from the zone of controlled irradiance, then an additional three samples of the identical preconditioned materials should be tested in the test mode in which the unusual behavior occurred. Data obtained from the improper tests noted above shall not be incorporated in the averaged data but the occurrence should be reported. The test method is not suitable if more than three of the six replicates tested show these characteristics.

6.2 The test method has proven sensitive to small variations in sample geometry, surface orientation, thickness (either overall or individual layer), weight, and composition. It is, therefore, critical that the replicate samples be cut, sawed, or blanked to identical sample areas, 3 by 3, +0, –0.03 in. (76.2 by 76.2, +0, –0.8 mm), and that records be kept of the respective weights with the individual test data. Evaluation of the obtained data together with the individual weights may assist in assessing the reasons for any observed variability in measurements. Preselection of samples with identical thickness or weight, or both, may reduce the variability but may not be truly indicative of the actual variability to be expected from the material as normally supplied.

6.3 The results of the test apply only to the thickness of the specimen as tested. There is not a common mathematical formula that can be used to calculate the specific optical density of one thickness of a material when the specific optical density of another thickness of the same material is known.

6.4 The test method is sensitive to small variations of the position of the specimen and radiometer relative to the radiant heat source.

6.5 Sensitivity to variations in composition requires that, when changing to another material to be tested, it may first be necessary to clean and remove from the walls the accumulated residues to assure that chemical or physical recombination with the effluents or residues produced by the pyrolysis does not affect the data obtained. Even when testing the same material, excessive accumulations of residue should not be permitted to build up since ruggedness tests have indicated that such serve as additional insulators tending to reduce normally expected condensation of the aerosol, thereby raising the measured specific optical density.

6.6 With resilient samples extreme care must be taken to assure that each replicate sample in its aluminum foil wrapper is installed so that each protrudes identically through the front sample holder opening. Unequal protrusion will subject the samples to different effective irradiances and to slightly different ignition exposures. Specimens that protrude excessively may drip or sag onto the burner, clogging the flame jets and thereby invalidate the test.

6.7 The measurements obtained have also proven sensitive to small differences in conditioning (see Section 9). Many materials such as carpeting and thick sections of wood, plastics, or plywood require long periods to attain equilibrium (constant weight) even in a forced-draft humidification chamber.

7. Apparatus

7.1 The apparatus shall be essentially as shown in Figs. 1 and 2. A more detailed description of suggested details is given in Annex A2. The apparatus shall include the following:

7.1.1 *Test Chamber*—As shown in Fig. 2, the test chamber shall be fabricated from laminated panels[6] to provide inside dimensions of 36 by 24 by 36 $\pm$ 1⁄8 in. (914 by 610 by 914 $\pm$ 3 mm) for width, depth, and height, respectively. The interior surfaces shall consist of porcelainenameled metal, or equivalent coated metal resistant to chemical attack and corrosion, and suitable for periodic cleaning. Sealed windows shall be provided to accommodatea vertical photometric system. All other chamber penetrations shall be sealed. When all openings are closed, the chamber shall be capable of developing and maintaining positive pressure during test periods, in accordance with 11.11.

7.1.2 *Radiant Heat Furnace*—As shown in Fig. 3, an electric furnace with a 3-in. (76.2-mm) diameter opening shall be used to provide a constant irradiance on the specimen surface. The furnace shall be located along the centerline

FIG. 1 Smoke Density Chamber

voltage transformer. The light source shall be mounted in a sealed and light-tight box. This box shall contain the necessary optics to provide a collimated light beam passing vertically through the chamber. The light source shall be maintained at an operating voltage required to provide a brightness temperature of $2200 \pm 100°K$.

7.1.5.2 The photodetector shall be a photomultiplier tube, with an S-4 spectral sensitivity response and a dark current less than 10^{-9} A. A set of nine gelatin compensating filters varying from 0.1 to 0.9 neutral density are mounted one or more as required in the optical measuring system to correct for differences in the luminous sensitivity of the photomultiplier tube. These filters also provide correction for light source or photomultiplier aging and reduction in light transmission, through discolored or abraded optical windows. An additional criterion for selection of photomultiplier tubes requires a minimum sensitivity equivalent to that required to give a full scale reading with only the No. 5 compensating filter in the light path. A light-tight box located directly opposite the light source shall be provided to mount the photodetector housing and the associated optics. A glass window shall be used to isolate the photodetector and its optics from the chamber atmosphere.

7.1.5.3 In addition to the above compensating filter, a neutral density range extender filter permitting the system to measure to Optical Density 6 is incorporated in the commercial version of the smoke density chamber. The accuracy of read-outs in the range above D_s 528 is affected by the excessive light scattering present in such heavy smoke concentration. Where D_s values over 500 are measured, it is necessary to provide a chamber window cover to prevent room light from being scattered into the photomultiplier, thereby providing an incorrect higher transmission value.

7.1.6 *Radiometer*—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.[7] The construction of the radiometer shall be as shown in Fig. 8. It shall have a stainless steel reflective heat shield with a 1½-in. (38.1-mm) aperature on the front and a finned cooler supplied with compressed air mounted on the rear to maintain a constant body temperature of $200 \pm 5°F$ ($93 \pm 3°C$).

7.1.7 *Thermocouple*—A thermocouple shall be fixed to the center of the inner surface of the wall opposite the door.

7.1.8 *Output Instrumentation*—The outputs of the radiometer shall be measured using a potentiometer and the results recorded. The photodetector output shall be measured with a potentiometer or other suitable instrument capable of measurement over the range of the apparatus. See Annex A1.

7.1.9 *Manometer for Chamber Pressure Measurements*—A simple water manometer with a range up to 6 in. (152 mm) of water shall be provided to monitor chamber pressure and leakage. The pressure measurement point shall be through a gas-sampling port in the chamber. A simple water column or relief valve shall be provided to permit control of chamber pressure (see A2.8).

7.1.10 *Multiple Flamelet Burner*—For a flaming exposure test, a six-tube burner, with construction details as shown in

equidistant between the front and back of the chamber, with the opening facing toward and about 12 in. (305 mm) from the right wall. The centerline of the furnace shall be about 7¾ in. (195 mm) above the chamber floor. The furnace control system shall maintain the required irradiance level, under steady-state conditions with the chamber door closed, of 2.20 ± 0.04 Btu/ft²·s (2.50 ± 0.05 W/cm²) for 20 min. The control system shall consist of an autotransformer or alternative control device, and a voltmeter or other means for monitoring the electrical input. Where line voltage fluctuations exceed ± 2.5, a constantvoltage transformer is required to maintain the prescribed irradiance level.

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

7.1.4 *Framework for Support of Furnace and Specimen Holder*—The furnace and specimen supporting framework shall be constructed essentially in accordance with Fig. 5.

7.1.5 *Photometric System*—The photometric system shall consist of a light source and photodetector, oriented vertically to reduce measurement variations resulting from stratification of the smoke generated by materials under test. The system shall be as shown in Figs. 6 and 7 and include the following:

7.1.5.1 The light source shall be an incandescent lamp operated at a fixed voltage in a circuit powered by a constant-

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[7] Gardon R., "An Instrument for the Direct Measurement of Intense Thermal Radiation," *Review of Scientific Instruments*, Vol 24, 1953, pp. 366–370.
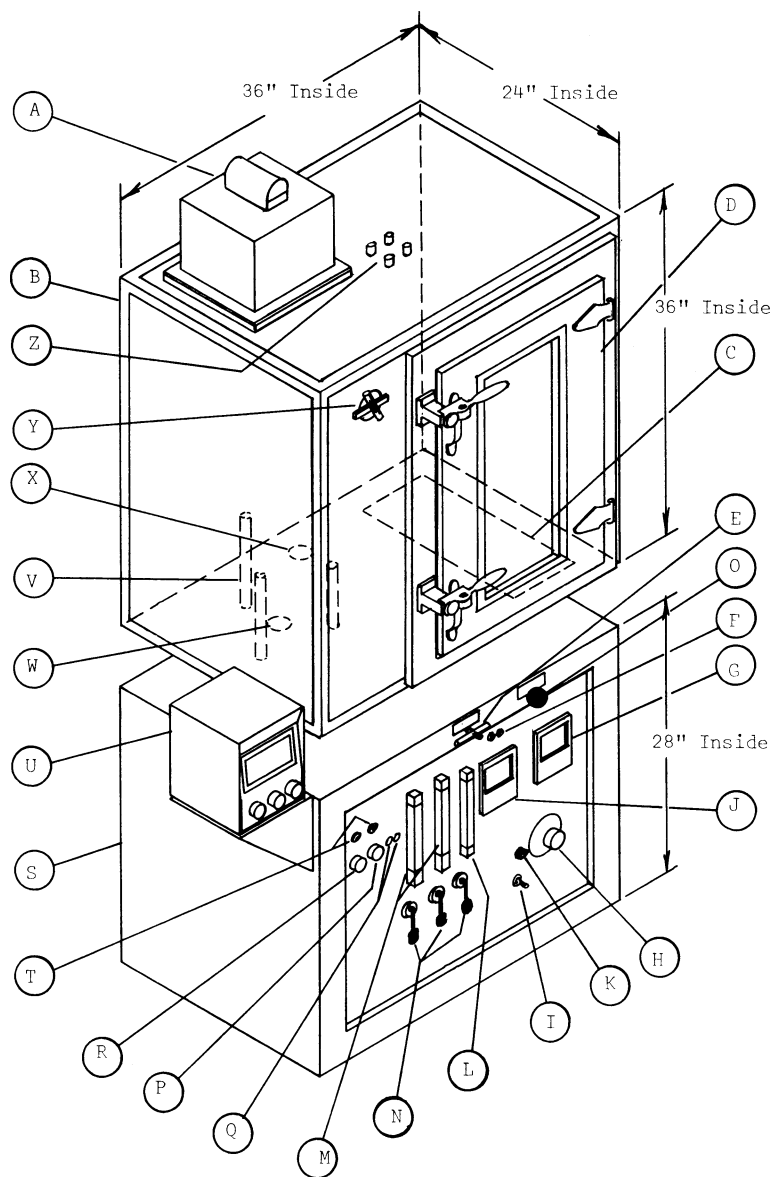
A—Photomultiplier tube housing
B—Chamber
C—Blow-out panel (in floor of chamber)
D—Hinged door with window
E—Exhaust vent control
F—Radiometer output jacks
G—Temperature (wall) indicator
H—Autotransformer
I—Furnace switch
J—Voltmeter (furnace)
K—Fuse holder (furnace)
L—Radiometer air flowmeter
M—Gas and air (burner) flowmeter
N—Flowmeter shutoff valves
O—Sample mover knob
P—Light source switch
Q—Light source voltage jacks
R—Line switch
S—Base cabinet
T—Indicating lamps
U—Microphotometer (photomultiplier)
V—Optical system rods
W—Optical system floor window
X—Exhaust vent damper
Y—Inlet vent damper
Z—Access ports

FIG. 2 Smoke Density Chamber Assembly

Fig. 4, shall be used. The burner shall be centered in front of and parallel to the specimen holder. The tips of the two horizontal tubes shall be centered ¼ ± ¹⁄₁₆ in. (6.4 ± 1.5 mm) above the lower opening of the specimen holder and ¼ ± ¹⁄₃₂ in. (6.4 ± 0.8 mm) away from the face of the specimen surface. Provision shall be made to rotate or move the burner out of position during nonflaming exposures. The fuel shall be propane having a 95 % purity or better. Filtered oil-free air and propane shall be fed through calibrated flowmeters and needle valves at 500 cm^3/min for air and 50 cm^3/min for the propane and premixed prior to entry into burner.

7.1.10.1 The small openings in the individual burner tiplets can readily be constricted or completely sealed by sample drippings or residue unless immediately removed while still

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HEATER FACE

1.5 in.
(38 mm)

FURNACE FACE

3 in.
(76 mm)

4 in.
(102 mm)

A—Stainless steel tube
B—Front insulating ring
C—Ceramic tube
D—Heater/plate 525 W
E—Stainless steel mounting screw
F—Insulating gasket
G—Stainless steel spacers
H—Stainless steel reflectors (3)
J—Center insulating disk
K—Insulating spacer ring
L—Rear insulating disk
M—Sheet metal screw (2)
P—Heater leads/porcelain beads

FIG. 3 Furnace Section

warm and viscous. To correct or prevent this situation, the user should prepare a set of six tempered spring steel wires each approximately 3½ in. (89 mm) long fabricated from 30-gage (0.014 in.) wire, with one end crimped or brazed to a knob to facilitate handling and to prevent possible loss of the wire by complete insertion. When a burner tipl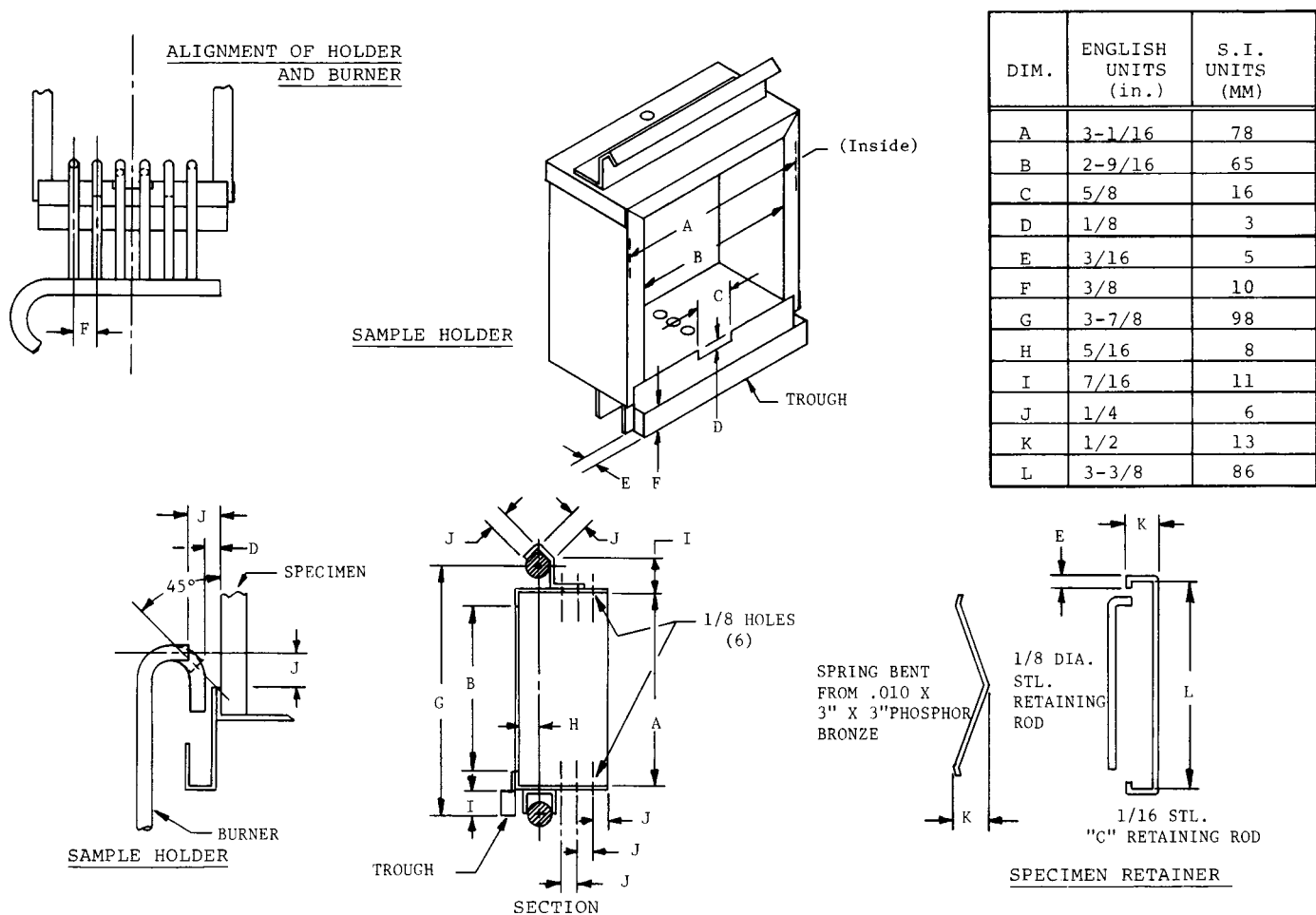et becomes clogged as indicated by flame extinguishment and inability to relight or by a distorted flame shape, thus invalidating the test, one of the wires should immediately be inserted and worked through several times to clear the obstruction. Immediately upon removal of the burner from the chamber while still warm, all six wires should be inserted in a like manner but should be left in place until the next time the burner is used. Where residues and clogging persist, a suitable solvent bath should be prepared so that the complete burner may be immersed and the wires used to loosen any hardened residue. Because of the construction, it is impossible to service the individual burner tiplets from the opposite direction, but because of ratio of diameters any obstruction pushed through the small diameter tiplets

should readily drop through the large diameter body tubing. Since most of these solvents are hazardous, proper precautions must be taken for handling and protection of personnel. If flammable, care must be taken to assure that "hot" burners are not immersed until cooled to room temperature.

8. Test Specimens

8.1 *Size*—The test specimens shall be 3 by 3, +0, −0.03 in. (76.2 by 76.2, +0, −0.8 mm) by the intended installation thickness up to and including 1 in. (25.4 mm). Materials greater than 1 in. (25.4 mm) thick shall be sliced to 1-in. (25.4-mm) thickness, and each original (uncut) surface tested separately if required under 8.3.1. The results are valid only for the thickness and form in which it is tested.

8.2 *Specimen Orientation*—If visual inspection of a material indicates a pronounced grain pattern, process-induced orientation or other nonisotropic property, a minimum of three specimens shall be tested for each orientation in each test mode. Exception: Where data are available and to show that

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DIM.	ENGLISH UNITS (in.)	S.I. UNITS (MM)
A	3-1/16	78
B	2-9/16	65
C	5/8	16
D	1/8	3
E	3/16	5
F	3/8	10
G	3-7/8	98
H	5/16	8
I	7/16	11
J	1/4	6
K	1/2	13
L	3-3/8	86

FIG. 4 Details of Specimen Holder and Pilot Burner

orientation of a specimen has no significant effect on test results, the specimen is only required to be tested in one orientation with each test mode (Note 1). When specimens require testing in different orientations, results of tests for each orientation shall be reported separately. Test results from specimens tested under different orientations shall not be used to obtain average values.

Note 1—It has been shown the orientation of carpet test specimens in terms of length and width (parallel and perpendicular to manufactured direction) has no statistically significant effect on the specific optical density obtained using this test method (**1**).[8]

8.3 *Specimen Assembly*:

8.3.1 The specimen shall be representative of the materials or composite and shall be prepared in accordance with recommended application procedures. Flat sections of the same thickness and composition are to be tested rather than curved, molded, or specialty parts. Substrate or core materials for the test specimens should be the same as those for the intended application. If a material or assembly may be exposed to a potential fire on either side, both sides should be tested. If an adhesive is intended for field application of a finish material or

substrate, the prescribed type of adhesive and the spreading rate recommended for the assembly of test specimen shall be used and reported.

8.3.1.1 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 (split) exposed surface, or on interior layers or surfaces, may be necessary. When supplementary tests are conducted for this purpose, the manner of performing such supplementary tests, and the test results, shall be included in the report with the conventional test results.

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

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

8.3.2.2 In the absence of a specified assembly system, 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/ft³(0.8 to 0.97 g/cm³), using recommended (or practical)

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[8] The boldface numbers in parentheses refer to the list of references at the end of this standard.

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FIG. 5 Furnace Support

application techniques and coverage rates. Tests shall also be conducted on the hardboard alone, and these values shall be recorded as supplemental to the measured values for the composite specimen.

8.3.2.3 Paints, adhesives, etc., intended for application to noncombustible substrate materials, shall be applied to the smooth face of ¼-in. (6.4-mm) thick inorganic reinforced cement board, nominally 110 ± 10 lb/ft^3 (1762 ± 160 kg/m^3) in density, using recommended (or practical) application techniques and coverage rates.

8.3.2.4 If fabrics or thin flexible films tend to shrink, to bunch, to blister, or to pull out from under the specimen holder during the test, the three test specimens shall be stapled with its aluminum foil wrapper to the inorganic insulation millboard backing. Five wire staples,[9] approximately ½ by ¼ by 0.02 in. (12.7 by 6.3 by 0.5 mm),[9] shall be positioned horizontally at the center, and at the center of the four quadrants.[9]

8.3.3 *Specimen Mounting*:

8.3.3.1 All specimens shall be covered across the back, along the edges, and over the front surface periphery with a single sheet of aluminum foil (0.001 ± 0.0005 in. or approximately 0.04 mm) with the dull side in contact with the specimen. Care shall be taken not to puncture the foil or introduce unnecessary wrinkles during the wrapping operation. Fold in such a way so as to minimize losses of melted material at the bottom of the holder. Excess foil along the front edges should be trimmed off after mounting. A flap of foil should be cut and bent forward at the spout to permit flow from melting specimens.

8.3.3.2 All specimens shall be backed with a sheet of ½-in. (12.7-mm) thick inorganic insulation millboard. The specimen and its backing shall be secured with the spring and retaining rod. A modified C-shape retaining rod or similar device shall be used with specimens from ⅝ to 1 in. (16 to 25 mm) thick. Do not deform compressible specimens below their normal thickness.

9. Conditioning

9.1 Predry specimens for 24 h at $140 \pm 5°F$ ($60 \pm 3°C$) and then condition to equilibrium (constant weight) at an ambient temperature of $73 \pm 5°F$ ($23 \pm 3°C$) and a relative humidity of 50 ± 5 % (see 6.7).

9.2 While in the conditioning chamber, specimens should be supported in racks so that air has access to all surfaces. Forced-air movement in the conditioning chamber will assist in accelerating the conditioning process.

10. Number of Test Specimens

10.1 Conduct three tests under flaming exposure and three tests under nonflaming exposure on each material (total of six specimens) in accordance with the conditions described herein.

10.1.1 When any result in any set of three replicates is such that it exceeds the minimum result by 50 % for no apparent reason, test an additional set of three replicates and report the average of all six results.

10.1.2 Where one or more of the three replicate tests demonstrate an unusual behavior such as detailed in 6.1, test three additional replicates. Average only the data from the successful tests.

10.2 Prior to use in a test, record the weight of each sample. Comparison of the weights with the individual optical density results may assist in assessing the reasons for the variability in measurements.

11. Procedure

11.1 Conduct all tests in a room or enclosed space having an

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[9] Bostitch B8, Swingline 888, Acc. Monarch No 1 FT, or similar, have been found satisfactory.

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A—Photomultiplier housing
B—Photomultiplier tube and socket
C—Upper shutter blade, with ND2 filter over one aperture
D—Lower shutter blade, with single aperture
E—Opal diffuser filter
F—Aperature disk
G—Neutral density compensating filter (from set of 9)
H—Lens, 7 diopter (2)
J—Optical system housing (2)
K—Optical system platforms (2)
L—Optical windows (2)
M—Chamber roof
N—Alignment rods (3)
P—Parallel light beam, 1.5-in. (37.5-mm) diameter
Q—Chamber floor
R—Optical window heater, silicone-fiberglass 50 W/115 V
S—Regulated light source transformer, 115/125 V-6 V
T—Adjustable resistor, light source, adjusted for 4 V
U—Light source

FIG. 6 Photometer Details

ambient temperature of 73 ± 5°F (23 ± 3°C) and relative humidity of approximately 50 % at the time of test. Take precautions to provide a means for removing potentially hazardous gases from the area of operation.

11.1.1 Caution is urged during use of apparatus to prevent explosion of pyrolyzates, particularly under nonflaming conditions. Good laboratory procedure is urged also to prevent exposure of the operator to smoke, particularly during removal of the sample from the chamber or in clean-up.

11.2 Clean the chamber walls whenever periodic visual inspection indicates the need.[10] Clean the exposed surfaces of the glass windows separating the photodetector and light source housing from the interior of the chamber, before each test (ethyl alcohol is generally effective). Charred residues on

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[10] An ammoniated spray detergent and soft scouring pads have been found effective.

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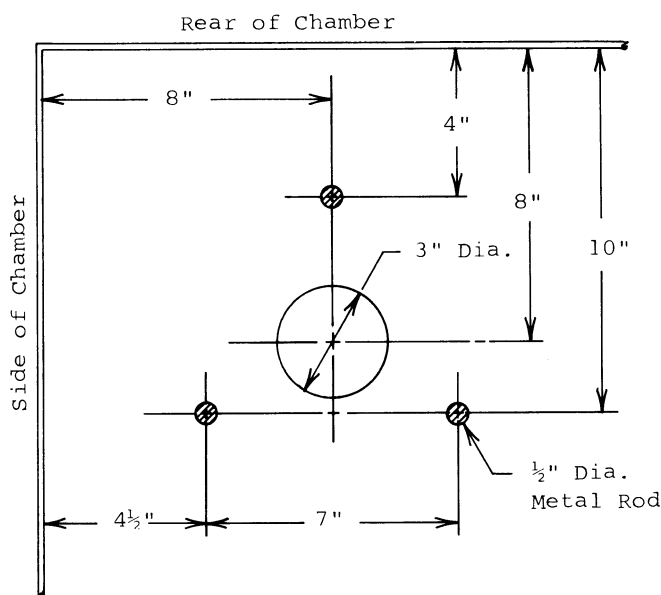
OPTICAL SYSTEM LOCATION
plan view
FIG. 7 Photometer Location

the specimen holder and horizontal rods should be removed between tests to avoid contamination.

11.3 During the warm-up period all electric systems (furnace, light source, photometer readout, etc.) should be on, the exhaust vent and chamber door closed, and the inlet vent open. 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 calibrating or testing. To increase chamber wall surface temperature to the stated level an auxiliary heater may be used but shall be removed prior to performing tests; conversely to decrease this temperature, the exhaust blower may be used to introduce cooler air from the laboratory. Standardize the furnace output irradiance at periodic intervals according to test experience (normally twice per test day).

11.4 A "blank" specimen holder, with the inorganic insulation millboard backing exposed should always be directly in front of the furnace except when displaced to the side by (1) the specimen holder during a test or (2) the radiometer during calibration. It should be returned immediately to this position when testing or calibration is completed to prevent excessive heating of the adjacent wall surface.

11.5 During the calibration, place the radiometer on the horizontal rods of the furnace support framework and accurately position in front of the furnace opening, by sliding and displacing the "blank" specimen holder against the pre-positioned stop. With the chamber door closed and inlet vent opened, adjust the compressed air supply to the radiometer cooler to maintain its body temperature at 200 ± 5°F (93° ± 3°C). Adjust the autotransformer setting so as to obtain the calibrated millivolt output of the radiometer corresponding to a steady-state irradiance of 2.2 ± 0.04 Btu/s·ft^2(2.5 ± 0.05 W/cm^2) averaged over the central 1.5-in. (38.1-mm) diameter area. Use the recorder or meter described in 7.1.8 to monitor the radiometer output. After the prescribed irradiance level has

reached steady-state, remove the radiometer from the chamber and replace with the "blank" specimen holder.

11.6 After the system has reached steady-state conditions, adjust the zero of the meter or recorder, or both. Adjust the amplifier sensitivity to obtain a full-scale reading of the photodetector (100 % transmittance) on the recorder or readout meter. Determine the "dark current" (0 % transmittance) on the maximum sensitivity range of the readout meter by blocking the light. Adjust the "dark current" reading to zero.

11.7 For nonflaming exposures, remove the multiple flame-let burner. For flaming exposures, position the burner across the lower edge of the specimen as described in 7.1.10. Check the burner distances relative to the "blank" specimen before fuel adjustment and ignition.

11.8 Before positioning the test specimen, flush the chamber with the door and exhaust and inlet vents open for about 2 min, and verify the starting temperature of the chamber, using the procedure described in 11.3.

11.9 Close the exhaust vent and blower. Place the loaded specimen holder on the bar support and push it into position in front of the furnace (with burner in position for flaming exposure) by displacing the "blank" holder. Quickly close the chamber door and simultaneously start the timer or recorder chart drive, or both. Close the inlet vent completely only when the photometer indicates the presence of smoke.

11.10 Record the light transmittance and the corresponding time either as a continuous plot with a multirange recorder or at time intervals no greater than 30 s with a multirange meter readout. Make and note the necessary full-scale range changes in decade steps.

11.10.1 The photometer used with this instrument shall have an accuracy of ±3 % or better of the maximum reading on any range. As such, the percentage error of a given reading becomes progressively worse at the lower portion of the scale. Avoid light transmittance on scale readings less than 10 by making the appropriate decade range change.

11.10.2 Some chambers are equipped with a switch that not only incorporates ranges of 100, 10, 1, and 0.1 but also ranges of 30, 3, and 0.3. With such an instrument the greatest accuracy would be achieved in light transmittance readings by making a range change in these intermediate ranges when the light transmittance reading reaches 30 on the 0-to-100 meter scale or 10 on the 0-to-33 scale.

11.11 Observe the increase in chamber pressure with the manometer described in 7.1.9. Use regulator (see A2.8) 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, open the inlet vent slightly to equalize the pressure. As a result of pressure rise, the fuel and air valves must be adjusted during the flaming test to maintain constant flow rate.

11.12 Record any observations pertinent to the burning and smoke generating properties of the material under test, in accordance with 13.1.6 and 13.1.7.

11.13 Continue the test for a period of 3 min after a minimum light transmittance value is reached or after an exposure of 20 min, whichever occurs first. If desired, the test may be conducted for periods in excess of 20 min, when
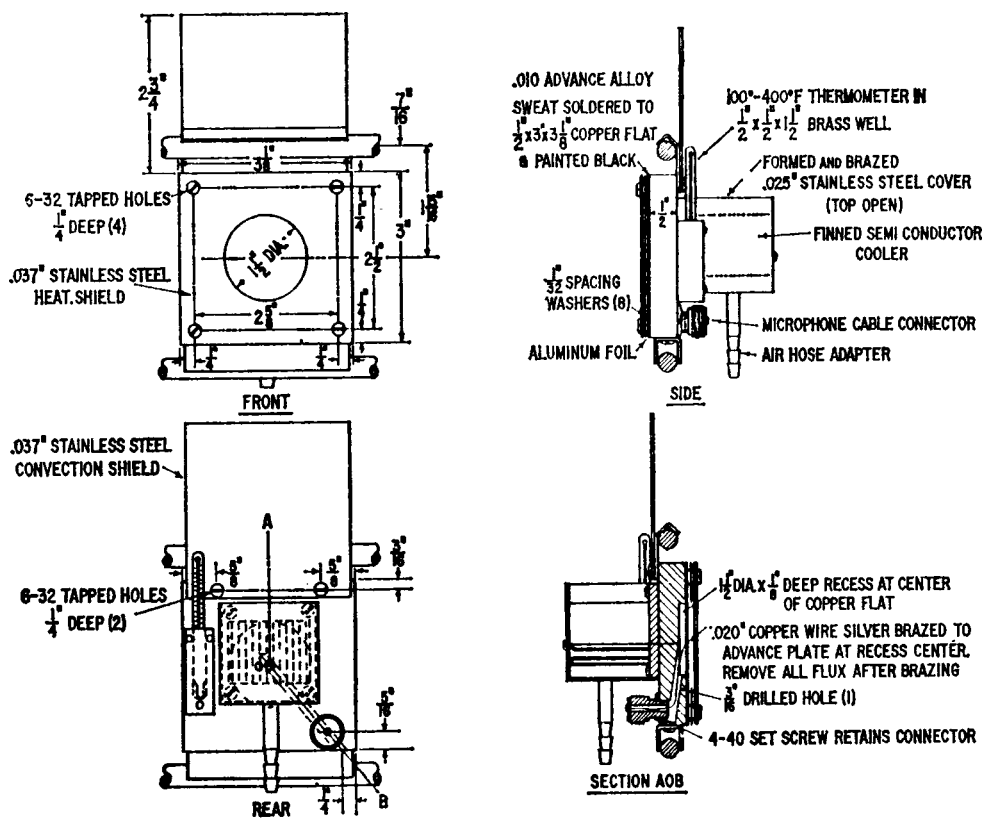
FIG. 8 Radiometer Details

minimum light transmittance levels have not been reached during the 20-min exposure.

11.14 If transmittance falls below 0.01 %, the chamber window should be covered with an opaque screen to avoid possible light-scattering effects from room light. Also any supplementary optical filter in the photometer system should 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.

11.15 Extinguish the burner on flaming exposures and start exhausting the chamber within 1 min after terminating the test (see 11.13 (Note 2)). Displace the specimen from the front of the furnace by pushing the "blank" specimen holder with the positioning rod. Continue to exhaust with the inlet vent open until maximum transmittance is reached. Record this transmittance value as the T_c, "clear beam" reading.

NOTE 2—In some cases the transmittance may increase somewhat and subsequently decrease to the ultimate minimum transmittance.

12. Calculation

12.1 Calculate specific optical density, D_s, at any given time as follows:

$$D_s = G\left[\log_{10}\left(100/T\right) + F\right]$$

where:
G = V/AL,
V = volume of the closed chamber, ft^3(or m^3),

A = exposed area of the specimen, ft^2(or m^2),
L = length of the light path through the smoke, ft (or m),
T = percent light transmittance as read from the light-sensing instrument, and
F = depends on the following:

(1) If the movable *filter* (see 7.1.5.3) is *in the light path* at the time that T is being measured, $F = 0$, and T is the actual percent transmittance.

(2) If the *filter* has been *moved out of the light path* (see 7.1.5.3 and 11.14) at the time that T is being measured, $F =$ *the known optical density of the filter* (see A1.1.4), and T is an *apparent* percent transmittance.

(3) If the optical system is *not equipped* with a *movable filter* in accordance with 7.1.5.3, $F = 0$, and T is the actual percent transmittance.

12.1.1 For an instrument constructed in accordance with this standard, corrections for the volume of the furnace assembly and the volume included in the door recess are generally less than 1 %. As such, $G = 132$.

12.1.2 A table for D_s versus actual percent light transmittance is given in Appendix X2. The D_s values above 528 are based on an assumed optical density of 2.00 for the movable filter.

12.2 Calculate the maximum specific optical density, D_m, using the equation in 10.1 with a light transmittance corresponding to the minimum level reached during the test.

12.2.1 Similarly, calculate D_c using the T_c value.

12.2.2 Calculate D_m(corrected) as follows:

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

12.3 For systems without "dark current" cancellation or "blank adjust" provisions, a correction must be made for any light transmittance reading, T, approaching the dark current value, T_d. Calculate the corrected light transmittance, T', as follows:

$$T' = 1 - \frac{1 - T}{1 - T_d} = \frac{T - T_d}{1 - T_d}$$

and is used for the specific optical density calculations described in 12.1 and 12.2.

12.4 Determine t_{D_m}, the time in minutes for the smoke to accumulate to the maximum specific optical density.

12.5 When the test is continued beyond the standard 20-min exposure, make all calculations in accordance with 12.1-12.4 and identify the results as "Extended Exposure."

13. Report

13.1 Report the following information:

13.1.1 Complete description of the material tested including: type, manufacturer, shape, thickness, or other appropriate dimensions, weight or density, coloring, etc.

13.1.2 Complete description of the test specimens, including: substrate or core, special preparation, mounting, specimen orientation, etc.

13.1.3 Information regarding the test specimen, conditioning procedure and the duration of conditioning.

13.1.4 Number of specimens tested.

13.1.4.1 When nonisotropic materials are not tested for each orientation, information on the data and appropriate criteria used to justify the use of only one orientation shall be included

(see 8.2). Such information shall include the source and availability of the data.

13.1.5 Test conditions: type of exposure, the exposure period, and temperature of chamber wall.

13.1.6 Observations of the behavior of the specimen during test exposure, such as delamination, sagging, shrinkage, melting, collapse, etc., including the time of such occurrence. The time of any change in exposure mode should be noted.

13.1.7 Observations of the smoke-generating properties of the specimens during exposure, such as color of the smoke, nature of the settled particulate matter, etc.

13.1.8 A tabulation or curve of time versus either percent transmittance or D_s (rounded to two significant figures) for each run of the three test specimens.

13.1.9 Test results rounded to two significant figures as described in Section 12 including the average and range on each set of specimens for D_m with time of occurrence, and D_m(corr).

NOTE 3—Prior to the adoption of this test method, it was customary to report the maximum smoke accumulated as D_m(corr), and for that reason it has been included as a part of the test report. Subsequently, a statistical analysis of the round-robin data upon which the precision statement is based, showed that the D_m values were more uniform. Therefore, it is required that both D_m and D_m (corr) be reported.

14. Precision and Bias

14.1 *Precision*:

14.1.1 Tables 1 and 2 are calculated from the results obtained when 25 materials were tested by 20 laboratories in a round-robin study conducted by ASTM Subcommittee E05.02, following a prior draft version of this method. That study indicated several sections of the test procedure that required

TABLE 1 Precision Statement for D$_m$—Flaming[A]

Material	Coefficients of Variation, %		Relative Precision, %	
	Within a Laboratory	Between Laboratories	Within a Laboratory (R_1)	Between Laboratories (R_2)
Hardboard, unfinished, ¼ in.	21.2	10.7	33.9	45.1
Particleboard, untreated, ⅜ in.	29.7	25.3	47.5	84.7
Lauan hardwood, plywood, unfinished, grade AD, ¼-in.	25.2	24.5	40.3	78.9
Hemlock, untreated, ¾-in.	24.8	24.5	39.7	78.6
Hemlock, treated, ¾-in.	26.2	11.9	41.9	53.2
Red oak, ¾-in.	27.2	39.3	44.4	117.7
Acoustical ceiling tile, untreated, ½-in.	22.3	24.4	35.7	76.5
Nonacoustical ceiling tile, untreated, ½-in.	26.9	28.8	43.1	90.8
Standard gypsum board, ½-in.	18.0	35.6	28.8	102.9
¹⁄₃₂-in. high-pressure standard decorative laminate, urea glue, on ¾-in. untreated particleboard	17.2	23.1	27.5	69.7
¹⁄₃₂-in. high-pressure, fire retardant decorative laminate, resorcinol adhesive, on ¾-in. treated particleboard	9.3	14.5	14.8	42.8
Linoleum	9.5	14.6	15.2	43.2
Wool plush carpet	15.4	10.2	24.7	37.4
Polyester twist carpet	19.6	13.5	31.4	48.9
Nylon twist carpet	3.6	10.9	5.7	30.8
Acrylic carpet	7.5	14.1	12.0	41.0
Fiber glass-reinforced brominated polyester sheet	11.8	9.2	18.9	31.7
Poly(vinyl chloride) flooring	14.3	9.1	22.9	34.1
Poly(methyl methacrylate) sheet	16.9	24.1	27.0	72.0
Flexible polyurethane foam, high resiliency, ½-in.	29.6	23.6	47.3	80.7
Rigid polyisocyanurate foam, ½-in.	6.2	13.4	10.0	38.4
NBS Standard Reference Material 1007a[B]	6.5	7.6	10.4	23.0

[A] Precision statements for polystyrene sheet and fiber glass-reinforced polyester sheet are not given because the D_m values fell outside the range of the instrument.
[B] The average D_m value obtained by 20 laboratories testing 3 samples each (60 samples) was 433.

TABLE 2 Precision Statement for D_m—Nonflaming[A]

Material	Coefficients of Variation, %		Relative Precision, %	
	Within a Laboratory	Between Laboratories	Within a Laboratory (R_1)	Between Laboratories (R_2)
Lauan hardwood plywood, unfinished, grade AD, ¼-in.	5.6	10.7	8.9	30.9
Untreated hemlock, ¾-in.	16.4	14.1	26.2	47.1
Hemlock, treated, ¾-in.	32.1	11.4	51.4	60.4
Red oak, ¾-in.	7.7	21.1	12.3	59.7
Acoustical ceiling tile, untreated, ½-in.	9.3	9.9	14.9	31.3
Nonacoustical ceiling tile, untreated, ½-in.	13.3	14.6	21.4	45.7
Standard gypsum board, ½-in.	5.6	12.3	8.9	35.3
¹⁄₃₂-in. high-pressure standard decorative laminate, urea glue, on ¾-in. untreated particleboard	6.2	11.9	9.9	34.5
¹⁄₃₂-in. high-pressure fire-retardant decorative laminate, resorcinol adhesive, on ¾-in. treated particleboard	20.1	30.2	32.1	89.7
Wool plush carpet	9.1	14.0	14.6	41.6
Polyester twist carpet	9.6	8.8	15.4	28.8
Nylon twist carpet	8.3	14.0	13.8	41.1
Acrylic carpet	6.8	9.4	10.9	28.9
Fiber glass-reinforced brominated polyester sheet	4.6	10.0	7.4	28.6
Poly(vinyl chloride) flooring	6.3	13.8	10.0	39.5
Polystyrene sheet	15.0	12.8	24.1	42.8
Poly(methyl methacrylate) sheet	24.0	29.9	38.5	91.5
Fiber glass-reinforced polyester sheet	7.1	5.7	11.3	19.4
Flexible polyurethane foam, high resiliency, ½-in.	10.1	10.6	16.2	33.6
Rigid polyisocyanurate foam, ½-in.	11.9	18.9	19.0	55.8
NBS Standard Reference Material 1006[B]	3.1	5.5	5.0	16.0

[A] Precision statements for hardboard, unfinished, ¼-in.; particleboard, untreated, ⅜-in.; and linoleum are not given because the D_m values fell outside the range of the instrument.

[B] The average D_m value obtained by 20 laboratories testing 3 samples each (60 samples) was 164.

additional description, and this version has been revised accordingly. It is reasonable to expect that this version of the method will provide better precision than that tabulated.

14.1.2 The precision statements in these tables are expressed as a percentage of the average D_m of each material and are based on only the validated results (see Section 3) from the three replicates submitted to each laboratory.

14.1.3 *Coefficient of Variation*—The ratio of either the "within laboratory" or "between laboratories" standard deviation to the overall average D_m value for the material, expressed as a percent.

14.1.4 *Relative Precision*:

14.1.4.1 *Repeatability, R_1*—The critical difference within which two averages of three specimens each, obtained on the same material by a single operator using the same instrument, can be expected to lie 95 % of the time because of random variation within a laboratory.

14.1.4.2 *Reproducibility, R_2*—The critical difference within which two averages of three specimens each, obtained by two different operators, using different instruments in different laboratories, can be expected to lie 95 % of the time because of the random variations within and between laboratories.

14.2 *Bias*—The bias is unknown because the value of specific optical density obtained in this procedure is defined only in terms of this test method.

15. Keywords

15.1 fire; fire-test response standard; smoke; smoke chamber; smoke density; smoke obscuration; solids; specific optical density

ANNEXES

(Mandatory Information)

A1. CALIBRATION OF TEST EQUIPMENT

A1.1 Photometric System

A1.1.1 A properly used photometer of the type described in this document is an inherently linear device provided that linear electronic measuring and recording equipment has been used. The linearity of absorption measurements is not dependent upon critical beam collimation; however, collimation of the optical beam may be of importance in cases where light scatter takes place, as often occurs in smoke aerosols. Because of this, the following instructions are included for use in cases where the photometer beam must be realigned following replacement of the light source or some accidental misalignment.

A1.1.2 *Alignment*:

A1.1.2.1 Prepare an opaque templet about 4½ in. (115 mm) in diameter with a centered 2-in. (51-mm) diameter drawn circle.
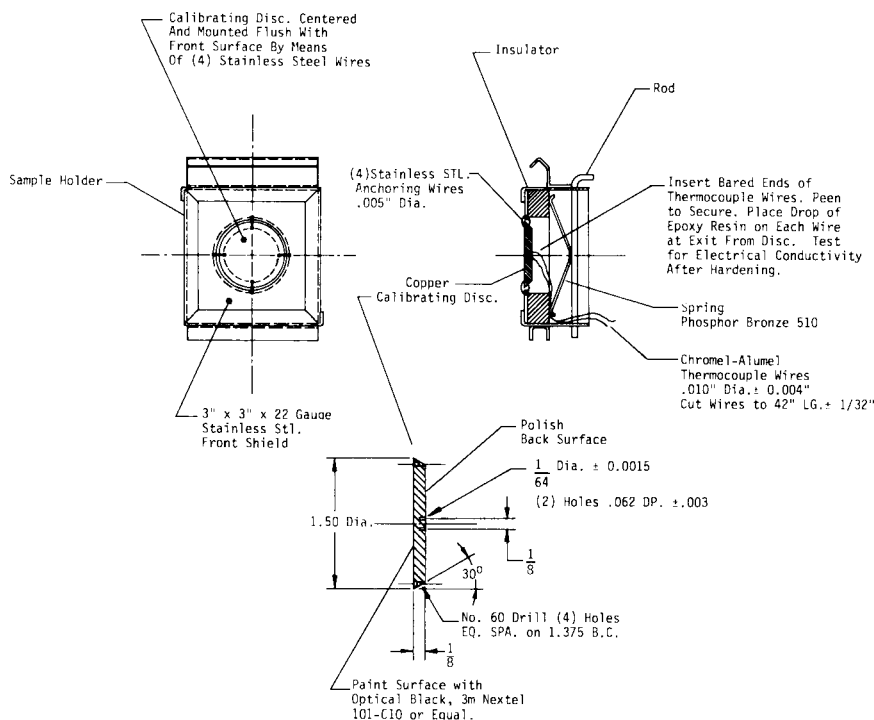
FIG. A1.1 Copper Disk Calorimeter

A1.1.2.2 Attach the templet with transparent tape to, and centered on, the upper optical window. With the optical system in its normal operational mode, observe the projected image on the templet. A properly aligned beam will completely fill the 2-in. (51-mm) circle with some spill-over. Because of the filament, the pattern will not be a perfect circle. If the pattern is too large or too small, the lower lens will require adjustment. Remove the cover from the light source enclosure. If the pattern is not centered, it will require repositioning of the light source or slight readjustment of the lens mount in its track. The lens position may be optimized by slight adjustment until the maximum photometer reading is obtained, whereupon it is locked. Replace the enclosure cover, making sure that all screws have been tightly seated.

A1.1.2.3 Switch off the photometer and remove the cover from the roof-mounted optical enclosure. Remove the compensating filter holder from the lens mount and observe the converging beam of light. A properly focused and aligned beam will form a small intense spot at the disk aperture of the photomultiplier housing projecting into the roof of the enclosure. If the beam is misaligned or not properly focused, loosen the lens mount screws very slightly and carefully refocus. Tighten the screws and recheck the light spot. Remount the compensating filter holder into the lens mount and replace the enclosure cover. All screws must be replaced to prevent light leaks.

A1.1.3 *Linearity Check*—The photometer used with this instrument should have an accuracy of ± 3 % of the maximum reading on any range. It involves a spectral band quite similar to that corresponding to human vision. This is defined by the operating condition of the lamp source and the spectral sensitivity of the photodetector. Since no precise control is maintained over the size of this spectral band, it would be necessary, if accurate calibration were to be attempted, to make use of filters with constant transmission over a spectral band of at least 350 to 750 nm. Such filters are not readily available. Because of this and the inherent linearity of a properly constructed photometer and measuring circuit, it is not recommended that the test method user attempt precise calibration of the instrument over its operating range. The following rough calibration procedure is, however, recommended as a means to ensure that no gross failure of the photometric measuring system has occurred:

A1.1.3.1 Complete alignment as in A1.1.2.

A1.1.3.2 With the photometer beam blocked, determine that the instrument shows zero transmission on all the normal photometer ranges without removal of the range extension filter from the photometer head.

A1.1.3.3 Measure the transmission of a neutral density filter of nominal optical density of 3.0 which has been previously calibrated in another smoke density photometer. The two transmission measurements should agree within 5 % of the mean of the two measurements. Failing such agreement, investigate to determine the reason for the discrepancy.

A1.1.4 *Range Extension Filter*—If equipped with the normal commercial microphotometer with incorporated dark current or blank adjust features, the system can only measure to 0.01 % transmittance, equivalent to a specific optical density of 528. To permit extension beyond this range, the commercial system is equipped with a glass ND2 filter in the shutter assembly. Determine the precise transmission of this filter as follows: With the optical system adjusted as stated in 11.5 and leaving the filter in the optical path, allow the chamber to stabilize at the operating temperature (35°C). Place over the lower window a white cloth or tissue sufficiently thick so as to give a "midscale" reading when the photometer range switch

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TABLE A1.1 Correction Factors for Range Extension Filter ND2 Neutral Density Filter Removal Correction Factors[A]

Meter indication, %T	Correction factor C_f	Optical density of neutral density filter, log $P_o/P=D$	Meter indication, %T	Correction factor C_f	Optical density of neutral density filter, log $P_o/P=D$
31	−27.4	1.79	51	+1.1	2.01
32	−25.6	1.81	52	+2.2	2.02
33	−23.8	1.82	53	+3.3	2.025
34	−22.1	1.83	54	+4.4	2.03
35	−20.4	1.845	55	+5.5	2.04
36	−18.8	1.86	56	+6.5	2.05
37	−17.3	1.87	57	+7.5	2.06
38	−15.7	1.88	58	+8.5	2.064
39	−14.2	1.89	59	+9.5	2.07
40	−12.8	1.90	60	+10.5	2.08
41	−11.4	1.91	61	+11.4	2.086
42	−10.0	1.92	62	+12.3	2.09
43	−8.6	1.93	63	+13.2	2.10
44	−7.3	1.94	64	+14.2	2.107
45	−6.0	1.95	65	+15.0	2.114
46	−4.8	1.96	66	+15.9	2.12
47	−3.5	1.97	67	+16.8	2.13
48	−2.3	1.98	68	+17.6	2.135
49	−1.2	1.99	69	+18.5	2.14
50	0.0	2.00	70	+19.3	2.146

[A]Corrections are to be applied to the D_s values equivalent to the 0.01 to 0.001 %T and 0.001 to 0.00001 %T values only.

is set to the "1-scale." Adjust the micrometer knob to give an exact mid-scale reading (0.5 % transmittance). Rotate the range switch back to the" 100-scale" and move the range extension filter out of the optical path. Observe the meter reading. If the meter reading is 50 % T, the value of the filter is exactly optical density 2.0 and the preprinted conversion tables, Appendix X2, may be used directly. If the meter indication is high, the filter value is less than optical density 2.0, and if the meter indication falls below 50 % T the optical density exceeds 2.0. Determine the correction to be applied to the range extension D_s values in Appendix X2 from Table A1.1.

A1.2 Radiometer

A1.2.1 Calibrate the radiometer by comparing its voltage output when exposed to heat from the furnace to that of a copper disk calorimeter (see Fig. A1.1) (primary standard) when the latter is exposed to the same heat flux. Calibrate at four furnace settings, two above and two below the nominal 2.5-W/cm^2 set point of the test method. From this, draw a graph, plotting the heat flux received by the radiometer against its voltage output. The procedure and calculations are as follows:

A1.2.2 With the furnace operating at a voltage setting between 90 and 95 V place the radiometer on the support rods so that it is positioned and oriented exactly as a test specimen relative to the furnace. Adjust the air flow to the radiometer cooler to maintain the body temperature of the radiometer at 200 ± 5°F (93 ± 3°C).

A1.2.3 Allow the furnace and radiometer output and body temperature to equilibrate until a steady-state, millivolt-output of the radiometer is obtained.

A1.2.4 Remove the radiometer and place a cool rateof-heat rise copper disk calorimeter (Fig. A1.1) promptly in front of the furnace in the same position as in A1.2.2. Immediately thereafter, obtain a short (5 to 15-s) record of the temperature rise of the disk. Determine this temperature rise of the calorimeter by measuring the electrical output of the thermocouple attached to

the back of the disk, employing a recording potentiometer operating at a fast chart speed (1 in./s; 25 mm/s). Remove the calorimeter and allow it to cool back to room temperature.

A1.2.5 Adjust the furnace voltage to three additional settings and repeat steps A1.2.2-A1.2.4 for each setting.

A1.2.6 Choose the furnace settings so that the output of the radiometer, expressed in W/cm^2 of radiant heat received, brackets the value 2.50 W/cm^2.

A1.2.7 Relate the output of the radiometer, expressed in millivolts, to the linear portion of the temperature rise of the copper disk, for each furnace setting by the following calculations:

		Units
Q_r	= radiant heat received by radiometer,	W/cm^2
	= radiant heat received by copper disk,	
	= G (dT/dθ) = (G/k) × [d(mV)/dθ]	
where:		
dT/dθ	= rate of temperature rise of copper disk,	°C·s^{-1}
d(mV)/dθ	= slope of thermocouple millivolt output on recording potentiometer,	mV·s^{-1}
k	= thermocouple conversion constant	
	= 0.040 mV × °C^{-1} for Chromel-Alumel between 20°C and 40°C, and	mV·°C^{-1}
G	= constant for the particular disk used = Kmc/A_na,	
where:		
K	= conversion factor = 4.184,	W·s·cal^{-1}
m	= mass of copper disk, uncoated,	g
c	= specific heat of copper = 0.0927,	cal·g^{-1}·°C
A_n	= net area of exposed (blackened) face of copper disk	cm^2
	= A_g − nA_h,	
A_g	= gross area of exposed face,	cm^2
n	= number of holes for supporting wires,	
A_h	= area of each hole, and	cm^2
a	= radiation absorption of black coating on face of disk[11]	

NOTE A1.1—As an example of the procedure proposed, the equation for the radiant heat absorbed by a particular copper disk may be simplified, as follows:

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[11] Nextel velvet 101-C10 provides a radiation absorption characteristic (a) of 0.98. Nextel velvet 101-C10 and its replacement, Solar Absorber Coating ECP-2200, are no longer manufactured by 3M Company. Nextel is a registered trademark of the 3M Company.

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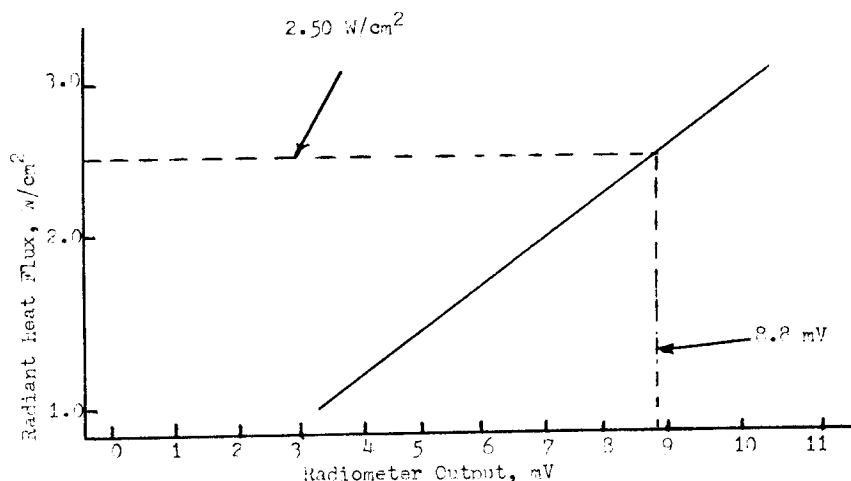
FIG. A1.2 Example—Calibration of Radiometer

Assume, as an example:

m = 29.78 g
A_g = 11.40 cm^2
n = 4
A_h = 0.008 cm^2

Then:

A_n = 11.37 cm^2
C = 0.0927 cal·g^{-1}·°C^{-1}
K = 4.184 cal·g^{-1}·°C^{-1}
k = 0.040 mV·°C^{-1}
a = 0.98

from which

$$Q_r = \frac{4.184 \times 29.78 \times 0.0927}{11.37 \times 0.98 \times 0.04} \times \frac{d(mV)}{d\theta}$$

$$= 25.91 \frac{d(mV)}{d\theta}$$

NOTE A1.2—The above is an example only and applies to a disk weighing 29.78 g and having a net area of 11.37 cm^2.

A1.2.7.1 The use of this copper disk calorimeter in calibrating a radiometer is illustrated by the following example:

Furnace Setting, V	Radiometer Output, mV	$d(mV)/d\theta$ Slope of Disk-Thermocouple Output, mV/s	Q_r, W/cm^2
97	3.72	0.043	1.11
102	7.30	0.081	2.10
112	9.50	0.105	2.7
117	10.13	0.108	2.80

From the above, a graph is obtained by drawing a best straight line through the plotted points and selecting the indicated output intersecting the line at 2.5 W/cm^2(see Fig. A1.2). From this graph, the output of the radiometer corresponding to a radiant heat flux of 2.50 W/cm^2 is obtained; in this case the value is 8.8 mV.

A1.2.8 Under normal continuous use conditions, the radiometer should be calibrated at least once every three months. Annual recalibrations should be required in all cases.

A1.2.9 The blackened face of the radiometer should be inspected frequently. In case the coating is blistered, cracked, discolored, or broken, the coating should be removed, the face of the radiometer cleaned, and a new coating applied. In this case, the recoated radiometer should be recalibrated before being used.

A1.2.10 The copper disk standard should be carefully handled when in use, and protected from surface contamination and mechanical abuse when stored. If the blackened face shows alterations as in A1.2.9 the coating should be removed and the face cleaned. The disk should then be reweighed and recoated and any appropriate corrections made in the calibration constant, G, before it is used again.

A1.3 Standard Materials

A1.3.1 For checking operational and procedural details of the equipment and method described herein, two standard materials may be used. The reference materials may be purchased from the Office of Standard Reference Materials, National Institute of Standards and Technology, Washington, DC 20234. Under nonflaming conditions, a single layer of alpha-cellulose (cotton linters) paper SRM1006, and under flaming conditions a plastic sheet, SRM1007a, 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.

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A2. CONSTRUCTION DETAILS

A2.1 Radiant Heat Furnace

A2.1.1 The furnace shown in Fig. 3 has been found to be suitable. The dimensions that are shown in Fig. 3 and the components to which they refer are critical. Other portions of the design are optional. The heating element consists of a coiled wire or other suitable electrical heating element capable of dissipating about 525 W, mounted vertically in a horizontal ceramic tube 3 in. (76.2 mm) in inside diameter by 3⅜ in. (85.7 mm) in outside diameter by 1⅝ in. (41.3 mm) long. The tube is bored out at one end to 3¹⁄₃₂-in. (77.0-mm) inside diameter and to a depth of ⅝ in. (15.9 mm) to accommodate the heating element. A ¹⁄₁₆-in. (1.6- mm) insulation paper gasket and two stainless steel reflectors are mounted behind the heating element. A ⅜-in. (9.5-mm) insulation millboard disk, provided with ventilation and lead wire holes, shall be positioned behind the heating element and used to center the assembly with respect to the front ⅜-in. (9.5-mm) insulation millboard ring by means of a 6-32 stainless steel screw. The adjustment nuts on the end of the centering screw shall provide proper spacing of the furnace components. The cavities adjacent to the heating element assembly shall be packed with glass wool. The furnace assembly shall be housed in a 4-in. (102-mm) outside diameter by 0.083-in. (2.1-mm) wall by 4⅛-in. (105-mm) long stainless steel tube. Two additional ⅜-in. (9.5-mm) insulation board spacing rings and a rear cover of ⅜-in. (9.5-mm) insulation board shall complete the furnace. The furnace shall 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 centerline of the furnace shall be about 7¾ in. (195 mm) above the chamber floor.

A2.2 Specimen Holder

A2.2.1 The specimen holder shall conform in shape and dimension to Fig. 4 and be fabricated by bending and brazing (or spot welding) 0.025-in. (0.6-mm) thick stainless steel sheet to provide a 1½-in. (38.1-mm) depth, and to expose a 2⁹⁄₁₆ by 2⁹⁄₁₆ in. (65.1 by 65.1-mm) specimen area. As described in 7.1.3, the holder shall have top and bottom guides to permit accurate centering of the exposed specimen area in relation to the furnace opening. A3 by 3-in. (76.2 by 76.2-mm) sheet of ½-in. (12.7-mm) inorganic insulation millboard, having a nominal density of 50 ± 10 lb/ft^3 (0.85 ± 0.17 g/cm^3) shall be used to back the specimen. A spring bent from 0.010 in. (approximately 0.25-mm) thick phosphorbronze sheet shall be used with a steel retaining rod to securely hold the specimen and millboard backing in position during testing.

A2.3 Support of Furnace and Specimen Holder

A2.3.1 The framework as shown in Fig. 5 shall have welded to it a 5-in. (127-mm) outside diameter, ¼-in. (6.4-mm) wall, 2-in. (50.8-mm) long horizontally oriented steel tube to support the radiant heat furnace described in 7.1.2. This support tube shall have provision to accurately align the furnace opening so that it is $1½ \pm ¹⁄₃₂$ in. (38.1 ± 0.8 mm) away from, parallel to, and centered with respect to the exposed specimen area.

A2.3.2 Adjustment screws shall be provided to align the furnace with reference to the specimen.

A2.3.3 The framework shall have two ⅜-in. (9.5-mm) diameter transverse rods of stainless steel to accept the guides of the specimen holder described in 7.1.3. The rods shall support the holder so that the exposed specimen area is parallel to the furnace opening. Spacing stops shall be mounted at both ends of each rod to permit quick and accurate lateral positioning of the specimen holder.

A2.4 Photometric System

A2.4.1 The photometric system shall consist of a light source and photosensitive element as defined in 7.1.5. The system shall be as shown in Figs. 6 and 7. The window in the chamber floor through which the light beam passes shall be provided with a ring-type electric heater mounted on the underside of the window out of the light path. The heater maintains the minimum window temperature at 125°F (52°C) on the inner surface of the window to minimize smoke condensation. The collimated beam inside the chamber shall have a path length of $36 \pm ⅛$ in. (914 ± 3 mm) and a sensing cross section of $1½ \pm ⅛$-in. (38 ± 3-mm) diameter (see Annex A1). A typical photomultiplier photometer system will require a high-voltage d-c 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 shall be capable of permitting the recording of reliable optical densities of at least 6.0, corresponding to transmittance values of 0.0001 % of the incident light (see Appendix X2).

A2.4.1.1 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.

A2.5 Radiometer

A2.5.1 The 200°F (98°C) body temperature of the radiometer shall be monitored with a 100 to 200°F (38 to 100°C) thermometer located as shown in Fig. 8 in a ½ by ½ by 1½-in. (12.7 by 12.7 by 38.1-mm) long brass or copper 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 shall be spraycoated with an infrared-absorbing black paint. The radiometer shall be calibrated calorimetrically in accordance with the procedure summarized in A1.2.

A2.6 Chamber Wall Thermocouple

A2.6.1 A thermocouple suitable for measuring a temperature of 35°C shall be mounted with its junction secured to the geometric center of the inner rear wall panel of the chamber using an electrical insulating disk cover and epoxy cement.

A2.7 Burner

A2.7.1 The multiple burner shall have six tubes with construction details as shown in Fig. 4 (Note A2.1). The six tubes shall be made from ⅛-in. (3.2-mm) outside diameter by

16

0.031-in (0.8-mm) wall stainless steel tubing. All tubes should be swaged at the tip to reduce the opening diameter to 0.055 in. (1.4 mm). The manifold section of the burner shall consist of ¼-in. (6.4-mm) outside diameter by 0.035-in. (0.9-mm) wall stainless steel tubing. The other end of the manifold is attached to a fitting in the chamber floor.

NOTE A2.1—The two outer tubes shall be directed normal to the surface of the specimen. The two inner tubes shall be directed at an angle of 45° downward. The two intermediate tubes shall be directed vertically downward into the trough of the specimen holder.

A2.8   Chamber Pressure Regulator

A2.8.1 A suitable pressure regulator may consist 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. (100 mm) below the water surface. The bottle should be located at or below the floor level of the chamber to avoid back-siphoning.

APPENDIXES

(Nonmandatory Information)

X1. ADDITIONAL CALCULATIONS

X1.1   The smoke chamber test results in a curve of specific optical density versus time. The maximum specific optical density, D_m, represents total smoke accumulation. Additional information that may be of value might include:

R_m — maximum rate of increase in specific optical density per minute, measured over any 2-min period, or 2 min from the start of the test.

t_{16} — time to reach D_s = 16 (T = 75 %), or other smoke level. This is a simple measurement of initial smoke generation.

SOI   — an abbreviation for the smoke obscuration index and incorporates the effects of total smoke, generation rate, and time to reach D_s = 16. It is calculated as follows:

$$SOI = \frac{(D_m)^2}{2000\, t_{16}} \left(\frac{1}{t_{0.3} - t_{0.1}} + \frac{1}{t_{0.5} - t_{0.3}} + \frac{1}{t_{0.7} - t_{0.5}} + \frac{1}{t_{0.9} - t_{0.7}} \right)$$

where $t_{0.1}$, $t_{0.3}$, indicate the time in minutes at which the smoke accumulation reaches 10, 30, etc., % respectively, of the maximum density D_m.

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X2. TABULAR CONVERSION OF PERCENT TRANSMITTANCE TO SPECIFIC OPTICAL DENSITY WHEN $G = 132$.

PARAMETERS AND TRANSMITTANCE RANGE	%T	0	1	2	3	4	5	6	7	8	9
		SPECIFIC OPTICAL DENSITY (D_s)									
MULTIPLIER: 100 with ND-2 Filter	90	6	5	5	4	4	3	2	2	1	1
	80	13	12	11	11	10	9	9	8	7	7
	70	20	20	19	18	17	16	16	15	14	14
	60	29	28	27	26	26	25	24	23	22	21
100 to 10 %T	50	40	39	37	36	35	34	33	32	31	30
	40	53	51	50	48	47	46	45	43	42	41
	30	69	67	65	64	62	60	59	57	55	54
	20	92	89	87	84	82	79	77	75	73	71
	10	132	127	122	117	113	109	105	102	98	95
MULTIPLIER: 10 with ND-2 Filter	90×10^{-1}	138	137	137	136	136	135	134	134	133	133
	80	145	144	143	143	142	141	141	140	139	139
	70	152	152	151	150	149	148	148	147	146	146
	60	161	160	159	158	158	157	156	155	154	153
10 to 1 %T	50	172	171	169	168	167	166	165	164	163	162
	40	185	183	182	180	179	178	177	175	174	173
	30	201	199	197	196	194	192	191	189	187	186
	20	224	221	219	216	214	211	209	207	205	203
	10	264	259	254	249	245	241	237	234	230	227
MULTIPLIER: 1 with ND-2 Filter	90×10^{-2}	270	269	269	268	268	267	266	266	265	265
	80	277	276	275	275	274	273	273	272	271	271
	70	284	284	283	282	281	280	280	279	278	278
	60	293	292	291	290	290	289	288	287	286	285
1 to 0.1 %T	50	304	303	301	300	299	298	297	296	295	294
	40	317	315	314	312	311	310	309	307	306	305
	30	333	331	329	328	326	324	323	321	319	318
	20	356	353	351	348	346	343	341	339	337	335
	10	396	391	386	381	377	373	369	366	362	359
MULTIPLIER: .1 with ND-2 Filter	90×10^{-3}	402	401	401	400	400	399	398	398	397	397
	80	409	408	407	407	406	405	405	404	403	403
	70	416	416	415	414	413	412	412	411	410	410
	60	425	424	423	422	422	421	420	419	418	417
0.1 to 0.01 %T	50	436	435	433	432	431	430	429	428	427	426
	40	449	447	446	444	443	442	441	439	438	437
	30	465	463	461	460	458	456	455	453	451	450
	20	488	485	483	480	478	475	473	471	469	467
	10	528	523	518	513	509	505	501	498	494	491
MULTIPLIER: 1 without ND-2 Filter	90×10^{-4}	534	533	533	532	532	531	530	530	529	529
	80	541	540	539	539	538	537	537	536	535	535
	70	548	548	547	546	545	544	544	543	542	542
	60	557	556	555	554	554	553	552	551	550	549
0.01 to 0.001 %T	50	568	567	565	564	563	562	561	560	559	558
	40	581	579	578	576	575	574	573	571	570	569
	30	597	595	593	592	590	588	587	585	583	582
	20	620	617	615	612	610	607	605	603	601	599
	10	660	655	650	645	641	637	633	630	626	623
MULTIPLIER: .1 without ND-2 Filter	90×10^{-5}	666	665	665	664	664	663	662	662	661	661
	80	673	672	671	671	670	669	669	668	667	667
	70	680	680	679	678	677	676	676	675	674	674
	60	689	688	687	686	686	685	684	683	682	681
0.001 to 0.00001 %T	50	700	699	697	696	695	694	693	692	691	690
	40	713	711	710	708	707	706	705	703	702	701
	30	729	727	725	724	722	720	719	717	715	714
	20	752	749	747	744	742	739	737	735	733	731
	10	792	787	782	777	773	769	765	762	758	755
	00	–	924	885	861	845	832	821	812	805	798

X3. SUGGESTED SMOKE DENSITY CHAMBER REPORT FORM

Sample Description _____

Test No. _____ Operator _____ Date _____

Time, min	%T	D_m	Time, min	%T	D_m	Time, min	%T	D_m
0.5			7.5			14.5		
1.0			8.0			15.0		
1.5			8.5			15.5		
2.0			9.0			16.0		
2.5			9.5			16.5		
3.0			10.0			17.0		
3.5			10.5			17.5		
4.0			11.0			18.0		
4.5			11.5			18.5		
5.0			12.0			19.0		
5.5			12.5			19.5		
6.0			13.0			20.0		
6.5			13.5					
7.0			14.0					

Operating Conditions:

Radiometer Reading _____ mV. @_____ W/cm²(date & time)_____

Furnace Voltage _____ Test Mode: _____ Pyrolysis: _____ w/Flaming:_____

Flowmeter Settings: Propane @ 50 cm³/min _____ Air @ 500 cm³/min _____

Chamber: Temperature _____ Pressure _____ in. H_2O

Chamber Surface Conditions _____

Sample:

Manufacturer, etc. _____

Preconditioning: Oven @ _____ °C _____ h Conditioner @ _____ °C _____ RH _____ h

Thickness _____ mm. Density _____ g/cm³

Weight: Initial _____ g   Final _____ g   Wt. Loss _____ g _____ %

Test Results:

Minimum Transmittance _____ %   Maximum D_m _____   Time to Max D_m _____ min

Clear Beam Reading _____ % T _____ D_m (corr) _____

Optional Presentation:

Max Rate of D_s/min _____   Time to reach D_s16 _____ min

Remarks:

_____

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X4. COMMENTARY

X4.1 Introduction

X4.1.1 The smoke density chamber test was developed at the National Bureau of Standards and was first described in an ASTM research symposium in 1967 (2). 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 (3-9).

X4.1.2 The method is somewhat like the box type test developed by Rohm and Haas (see Test Method D 2843 and Ref (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 material against another.

X4.1.3 Measurements made with the test relate to light transmission through smoke. No means are provided for predicting the effect of eye irritants in further limiting visual range. Limited information suggests that eye irritants might further reduce vision by 50 to 95 %.

X4.2 Features of Test Method

X4.2.1 Two exposure conditions are 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 of a product. The irradiance level of 2.5 W/cm^2 was selected as the highest for which most cellulosics would pyrolize without selfignition. This irradiance level is much lower than that which would exist in a compartment after flash-over. It more nearly simulates conditions in the initial stages of a fire.

X4.2.1.1 The basis of selection of a specimen irradiance level of 2.5 W/cm^2 was discussed in X4.2.1. A further comment on the uniformity of irradiance across the specimen surface seems desirable. 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. diameter central area of the specimen holder.

X4.2.1.2 Fig. X4.1 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 being a practical compromise, considering the likely use to which the test method might be applied.

X4.2.2 The primary measurement made during the conduct of the test is the amount of light transmitted as a fraction or percentage of the initial light transmitted by the optical system. The minimum % light transmitted value is, in turn, used to
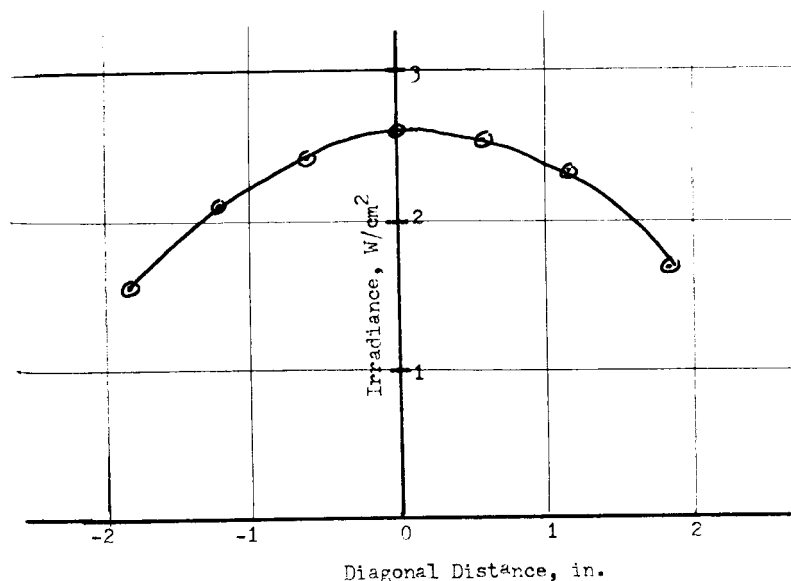

FIG. X4.1 Diagonal Survey of Irradiance at Specimen During Operation at Nominal 2.5 W/cm^2

calculate, in accordance with 12.1 of the test method, the maximum specific optical density, D_m, value. There is considerable advantage to using specific optical density as a value by which to evaluate results as compared to using percent light transmittance.

X4.2.2.1 The use of this unit of smoke measurement is based on Bouguer's law of light attentuation which is expressed as follows:

$$T = T_0 e^{-\sigma L}$$

where:
T = % flux transmittance,
T_0 = 100, the initial transmitted flux,
σ = attenuation coefficient, and
L = length of the optical path.

For a monodispersed aerosol, σ is found to be proportional to the product of size and number of particles. Defining log $(100/T)$ as being the optical density, d, it can then be developed that:

$$d = \log (100/T) = (\sigma T/2.303)$$

X4.2.2.2 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 engineering purposes, 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.

X4.2.2.3 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.

X4.2.3 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 specimen involved, the volume of the box, and the optical path length of the photometer. Specific optical density is without dimension, but its value must 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 lightobscuring properties of smoke that can be developed by the same product in other fire-involved areas,

different light paths, in another enclosure volume, on the assumption of uniform smoke-air mixing and under similar fire exposure conditions (**11**). At the present time, techniques for making these estimates 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.

X4.3 Factors Influencing the Test

X4.3.1 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:

X4.3.2 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.

X4.3.3 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; on the other hand, it also reduced air circulation past the specimen and thus inhibited open flaming combustion. As a result, the separation called for in A2.3 of 1½ ± ¹⁄₃₂ in. 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.

X4.3.4 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.

X4.3.5 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 applied to 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.

X4.4 Precision

X4.4.1 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.

X4.4.1.1 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 % 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.

X4.4.2 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 would be expected if another laboratory round-robin test should be conducted.

X4.4.2.1 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. Section 6 of the test method now contains such information. These data were also excluded when calculating the precision data presented in Section 14. 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 mea-surement capability of the photometer.

X4.5 Reporting of Results

X4.5.1 One of the obvious needs with a test method of this type is to consider ways in which the experimental data should be reported and used. Early draft versions of this standard contained a recommendation that a correction be applied to the measured D_m by subtracting the smoke deposit on the window following a test. In addition, the current version requires reporting D_m(corr). The reporting of D_m as a preferred measurement result is based on the following facts:

X4.5.1.1 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.

X4.5.1.2 Experience has shown that the determination of T_c used eventually to calculate D_m (corr), is subject to variations in operator technique during the chamber venting procedure.

X4.5.1.3 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).

X4.6 Limitations on Application of Smoke Measurement Data

X4.6.1 The smoke problems that develop during unwanted fires have been recognized for many years. Fire fighters are faced with it 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: (1) the extent to which the smoke measurement assesses the smoke hazard (12, 13); (2) the lack of a well-defined measurement method which could be shown to provide a technically valid means for smoke characterization; and (3) most materials or products, when burning, release large quantities of smoke, and there have been only limited ways of reducing smoke production.

X4.6.1.1 The first problem still exists, although as indicated in X4.2.2.1 there is a valid basis for consideration that this type of smoke measurement does in fact serve to measure the light attenuating properties of the smoke.

X4.6.1.2 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 unique and absolute measures of smoke production during building fires.

X4.6.1.3 The third problem 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.

X4.6.2 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 wellillustrated in Fig. X4.2. The indicated 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.

X4.6.3 The smoke density chamber provides a means for characterizing smoke production with an accuracy far in excess of any application requirements that could 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 original paper describing the test

FIG. X4.2 D_m for Spruce as a Function of Specimen Thickness Under Nonflaming Conditions

method (**2**) suggested one way these properties could be combined with D_m to yield a smoke obscuration index (SOI). Since then others have suggested refinement of the classification method. It seems that refinements such as these are only likely to be of significant value under the most carefully controlled fire safety conditions.

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