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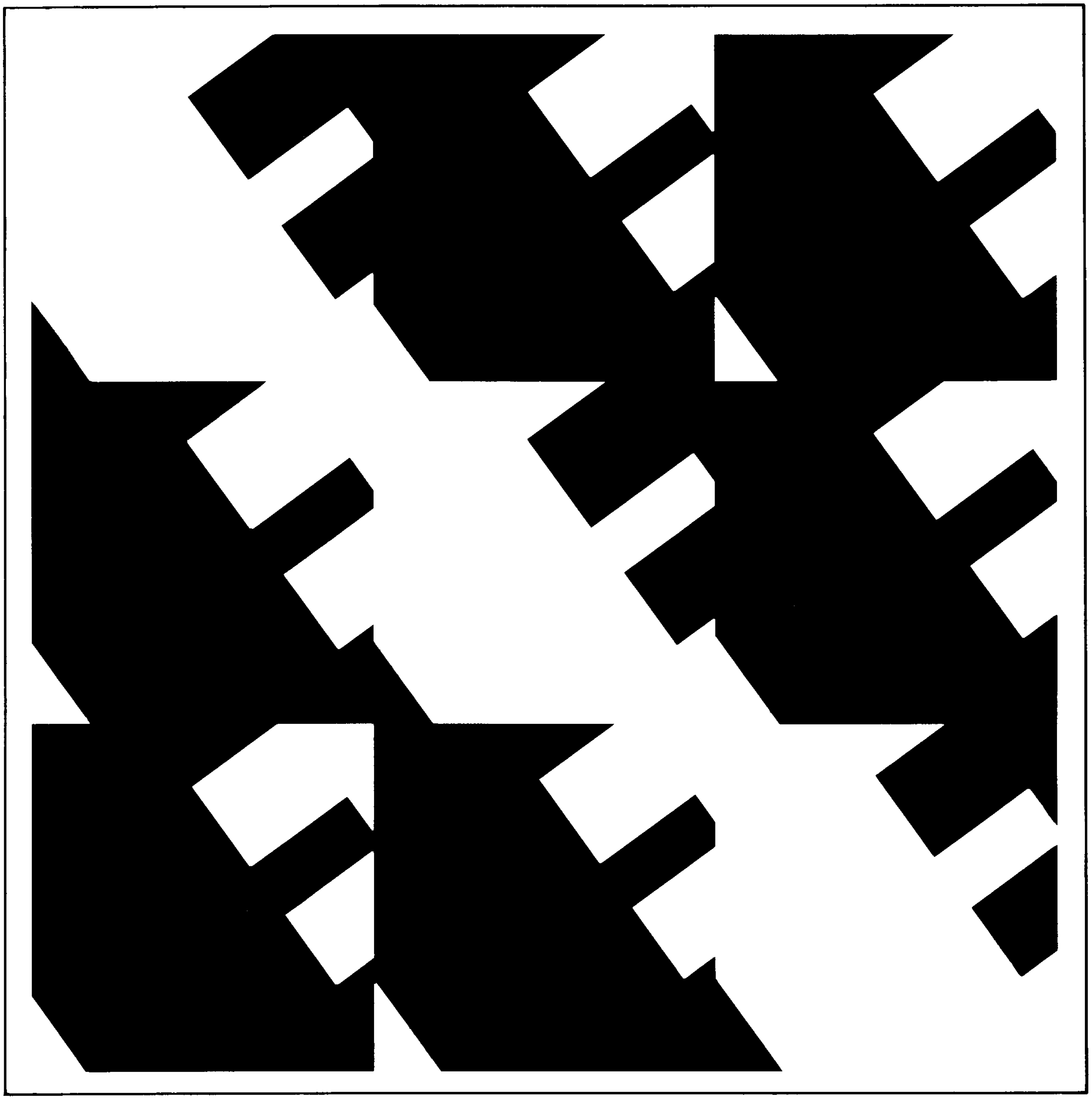
ANSI/IEEE Std 816-1987

IEEE Guide for Determining the Smoke Generation of Solid Materials Used for Insulations and Coverings of Electric Wire and Cable

ANSI/IEEE Std 816-1987



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IEEE Guide for Determining the Smoke Generation of Solid Materials Used for Insulations and Coverings of Electric Wire and Cable

Sponsor

Insulated Conductors Committee of the
IEEE Power Engineering Society

Approved March 22, 1984

IEEE Standards Board

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American National Standards Institute

The Institute of Electrical and Electronics Engineers, Inc
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Foreword

(This Foreword is not a part of ANSI/IEEE Std 816-1987, IEEE Guide for Determining the Smoke Generation of Solid Materials Used for Insulations and Coverings of Electric Wire and Cable.)

This guide was developed to aid wire and cable manufacturers in the study of the smoke generation characteristics of materials used in their products. Its intent is to provide improved materials and new polymers for wire and cable products. These small-scale laboratory tests are recommended for use in identifying promising materials for further study and large-scale testing. These tests are not meant to provide smoke-hazard assessment for end-use applications and are not intended as code criteria.

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Appendix A NBS Method 26

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1. Scope and References

1.1 Scope. These methods of test cover two laboratory procedures for measuring smoke generated by solid materials considered for use as insulations and coverings of electric wire and cable. The test methods are only applicable to evaluations of single materials as standard size molded samples.

1.1.1 In the NBS method, 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 (smoldering) decomposition or flaming combustion, or both. Results are expressed in terms of specific optical density, which is derived from a geometrical factor of optical density.

The test is conducted in two modes of operation:

1.1.2 (1) *Flaming.* Where pilot flame is applied to the sample in addition to irradiation from a heating element.

(2) *Smoldering.* Irradiation from a heating element is applied but the pilot flame is not used.

In the Arapahoe method, smoke and char are measured gravimetrically under dynamic (flow) conditions. Only a flaming mode of operation is provided. The sample is ignited by a microburner. It is a fundamental assumption that smoke weight can be used to estimate the smoke density as measured by optical smoke test methods such as the NBS chamber [4].[1]

1.2 References. This standard shall be used in conjunction with the following publications:

[1] ASTM C190-1985, Test Methods for Tensile Strength of Hydraulic Cement Mortars.[2]

[2] ASTM D618-1961 (81), Methods for Conditioning Plastics and Electrical Insulating Materials for Testing.

[3] GARDON, R. An Instrument for the Direct Measurement of Intense Thermal Radiation. *Review of Scientific Instruments.* vol 24, 1953, pp 366-370.

[4] KRACKLAUER, J. J., LEGG, R. E., and SPARKES, C. J. Interlaboratory Evaluation and Correlation Studies with the Arapahoe and NBS Smoke Chamber. *Proceedings of the 26th International Wire and Cable Symposium.* 1977, p 261.

[5] NBS Technical Note 708, *Interlaboratory Evaluation of Smoke Density Chamber.*[3]

2. Significance

2.1 These methods provide means for comparing the smoke generated by materials in the form, thickness, orientation, and quantity tested, under the specified exposure conditions.

2.2 Values determined by these tests are specific to the specimen material in the form, thickness, orientation, and quantity tested but shall not be considered inherent, fundamental properties of a given material.

2.3 The test methods of this standard are of a small-scale laboratory type. As such, they are intended to provide necessary guidance for laboratory research studies as in the development of improved compositions or the preliminary evaluation of new polymers. They are recommended for use in identifying materials that are promising for further study and larger-scale testing. It is emphasized, however, that these small-scale

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[1] The numbers in brackets correspond to the references listed in 1.2 of this standard.

[2] ASTM publications are available from the Sales Office, American Society for Testing Materials, 1916 Race Street, Philadelphia, PA 19103.

[3] NBS publications are available from the National Bureau of Standards, Department of Commerce, Washington, DC 20234.

laboratory tests do not encompass many factors important to real-life fire situations, and they do not provide a smoke-hazard assessment for materials in end-use circumstances. These tests are, therefore, not intended as code criteria and should not be used as such.

2.4 It is recognized that the ultimate basis for material selection and for code requirements is best provided by larger-scale tests that closely simulate the essential conditions of a particular intended use or application.

2.5 The small-scale test methods of this standard may prove useful for quality-control purposes after appropriate verification of the material(s) in question.

2.6 Test results obtained from individual materials can not be assumed to provide a useful prediction of performance of materials combined in composites, laminates, or finished wire and cable constructions.

3. NBS Method

3.1 Summary of Method

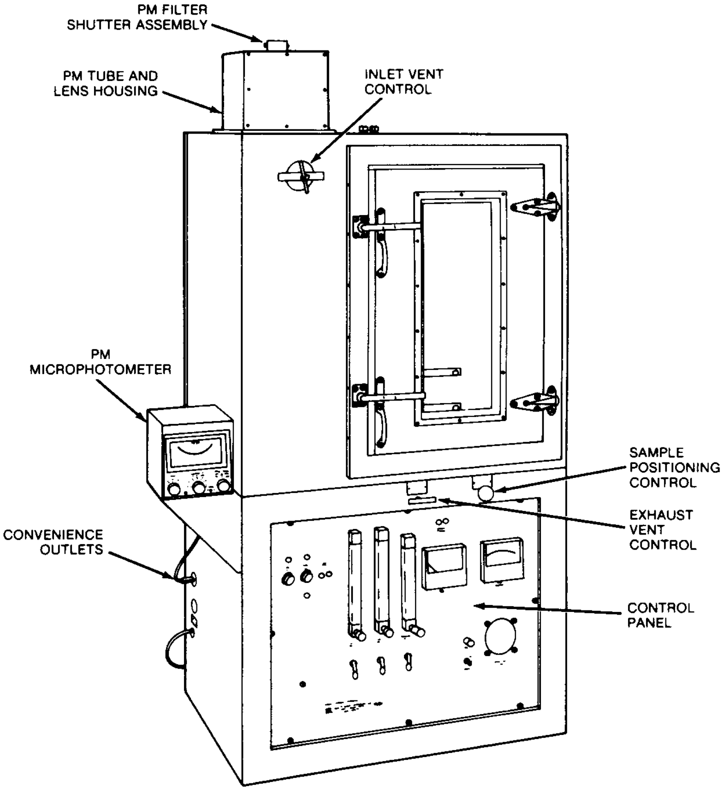
3.1.1 The National Bureau of Standards Smoke Density Chamber provides a fixed volume chamber in which the total smoke and effluent of a test specimen is accumulated and photometrically measured.

3.1.2 Two burning conditions are simulated in the smoke density chamber: radiant heating in the absence of a flame source and flaming combustion in the presence of supporting radiation.

3.1.3 The specimens are placed in a holder for the test. These specimens are 3 in by 3 in (76.2 mm by 76.2 mm) and can be of any thickness up to and including 1 in (25.4 mm). When the specimen is in the holder, the exposed area is $2\frac{9}{16}$ in by $2\frac{9}{16}$ in (65.1 mm by 65.1 mm).

3.1.4 In the nonflaming mode, the specimen is exposed to a radiant energy source of 2.2 Btu/$(\mathrm{s \cdot ft^2})$ [2.5 $\mathrm{W/cm^2}$] over an area of 1.5 in (3.8 cm) diameter in the center of the specimen.

Fig 1
Smoke Density Chamber



3.1.5 In the flaming mode, a six-tube burner applies a row of small flames over the lower edge of the exposed specimen area. The flames are in addition to the radiant energy source.

3.1.6 The cumulative smoke obscuration measurements are made using a collimated light beam from an incandescent light source. The intensity of light passing through the smoke is measured by a photomultiplier microphotometer system capable of detecting minute light level differences (up to 0.001% of the original transmitted light).

3.1.7 The smoke produced by the specimen results in reduced light transmittance, which can be expressed in specific optical density.

3.2 Test Apparatus

3.2.1 Smoke Density Chamber. The smoke density chamber is shown in Figs 1 and 2.[4]

3.2.2 Test Chamber

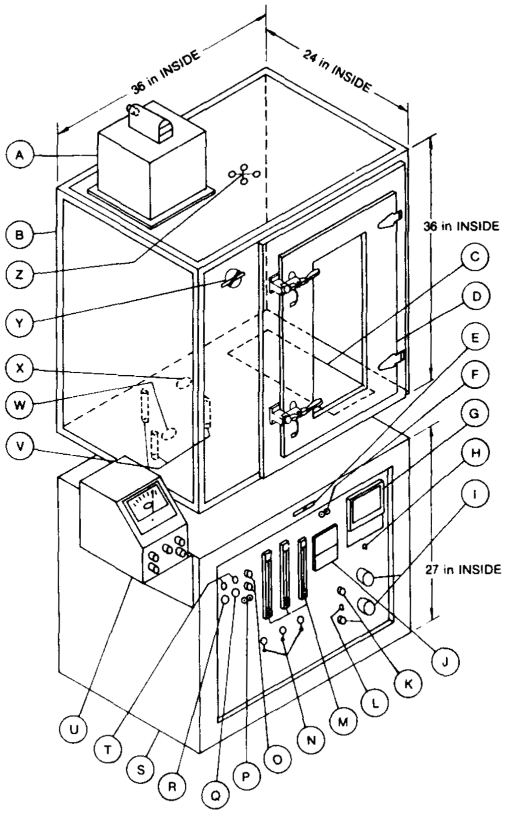
(1) The inside dimensions of the test chamber shall be 36 in (914 mm) high by 24 in (610 mm) deep and 36 in (914 mm) wide.

(2) The interior surfaces shall consist of porcelain-enameled metal, or equivalent metal with a coating resistant to chemical attack and corrosion, and suitable for periodic cleaning.

(3) Sealable openings shall be provided to accommodate a vertical photometer, power and signal connectors, air and gas supply tubes, an 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 thick [approximately 0.025 mm] or less) safety blowout panel, at least 125 in^2 (806 cm^2) in area, and a hinged front-mounted door with an observation port or window. All openings except the gas sampling taps, the positioning rod, and an inlet vent shall be located on the floor of the chamber. When all openings are closed the chamber shall be capable of developing and maintaining positive pressure during test periods.

3.2.3 Radiant Heat Furnace

(1) As shown in Fig 3 an electric furnace with a 3 in (76.2 mm) diameter opening shall be used to provide a constant radiance on the specimen surface. The furnace is to be located centrally along the long axis of the chamber with the opening facing toward and approximately 12 in (305 mm) from the right-hand wall. The centerline of the furnace shall be approximately 7¾ in (195 mm) above the chamber floor.



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

Fig 2
Smoke Density Chamber Assembly

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

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[4] A suitable commercially available chamber is Model J4-5800B Aminco-NBS Smoke Density Chamber made by The American Instrument Co, 8030 Georgia Ave, Silver Spring, MD 20910.

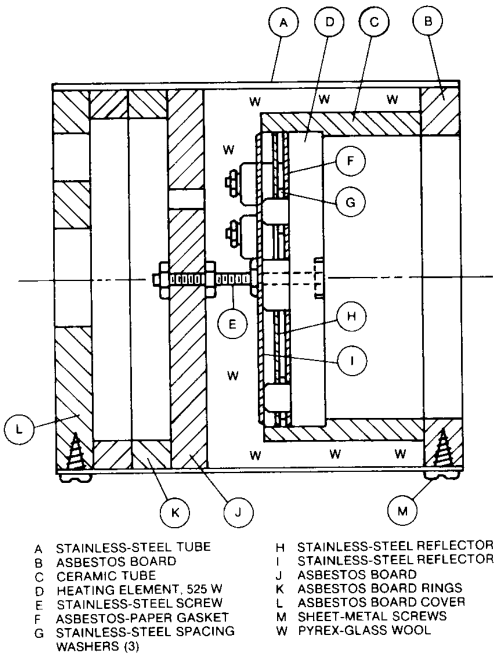


Fig 3
Furnace Section

control system shall consist of an autotransformer or alternate control device, and a voltmeter or other means for monitoring the electrical output. Where line voltage fluctuations are present, a constant-voltage transformer may be required to maintain the prescribed irradiance level.

3.2.4 Specimen Holder

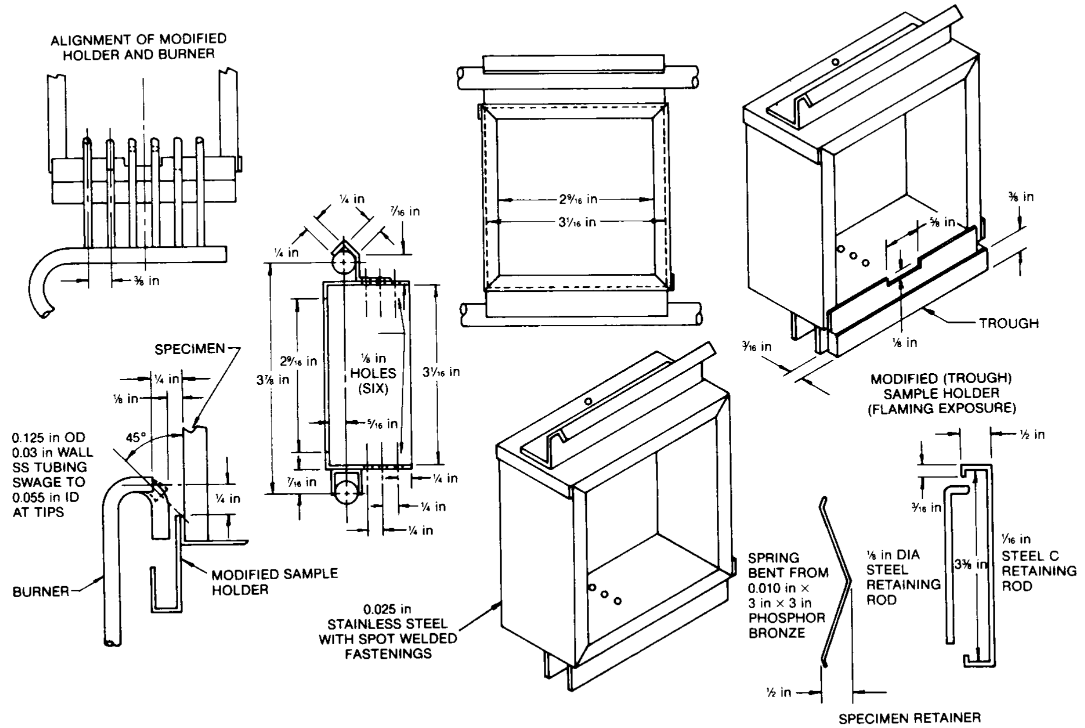
(1) Specimen holders shall conform in shape and dimension to that shown in Fig 4, and be fabricated to expose a 2 in by 9/16 in (65.1 mm by 65.1 mm) specimen area. For flaming exposure tests, and where melting occurs in nonflaming tests, a modified holder with trough shall be used. Also shown in Fig 4 are the spring and rods for retaining the specimen within the holders.

(2) The furnace and specimen supporting framework shall be constructed essentially in accordance with Fig 5. The specimen holder shown in Fig 4 will be located on the horizontal cylindrical rods shown in Fig 5 during the test.

3.2.5 Photometric System

(1) The photometric system shall consist of a light source and photodetector, oriented vertically to reduce variations in measurement brought about by stratification of the smoke generated by

Fig 4
Details of Specimen Holders and Pilot Burner



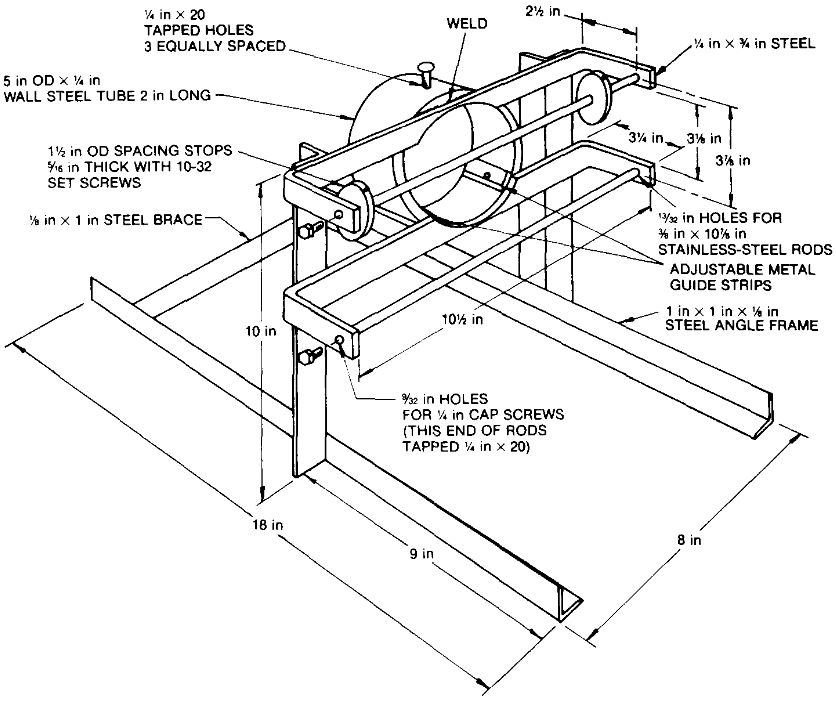


Fig 5
Furnace Support

materials under test. The system shall be as shown in Fig 6 and located as in Fig 7.

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

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

3.2.6 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 [3]. 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) aperture on the front and a finned cooler supplied with compressed air mounted on the rear to maintain a constant body temperature of 200 °F ± 5 °F (93 °C ± 3 °C).

3.2.7 Thermocouple. A thermocouple shall be provided for determining the chamber wall temperature prior to testing.

3.2.8 Portable Recorder or Readout Meter. The outputs of the radiometer and the thermocouples shall be monitored with a potentiometer or other suitable instrument capable of measurement over a range of five decades, or more.

3.2.9 Manometer for Chamber Pressure Measurements. 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 Appendix A). The pressure measurement point shall be through a gas sampling hole at the top of the chamber. A simple water column or relief valve shall be provided to permit control of the chamber pressure.

3.2.10 Multiple Flamelet Burner

(1) For a flaming exposure test, a six-tube burner, with construction details as shown in Fig 4, shall be used.

(2) The burner shall be centered in front of and parallel to the specimen holder. The tips

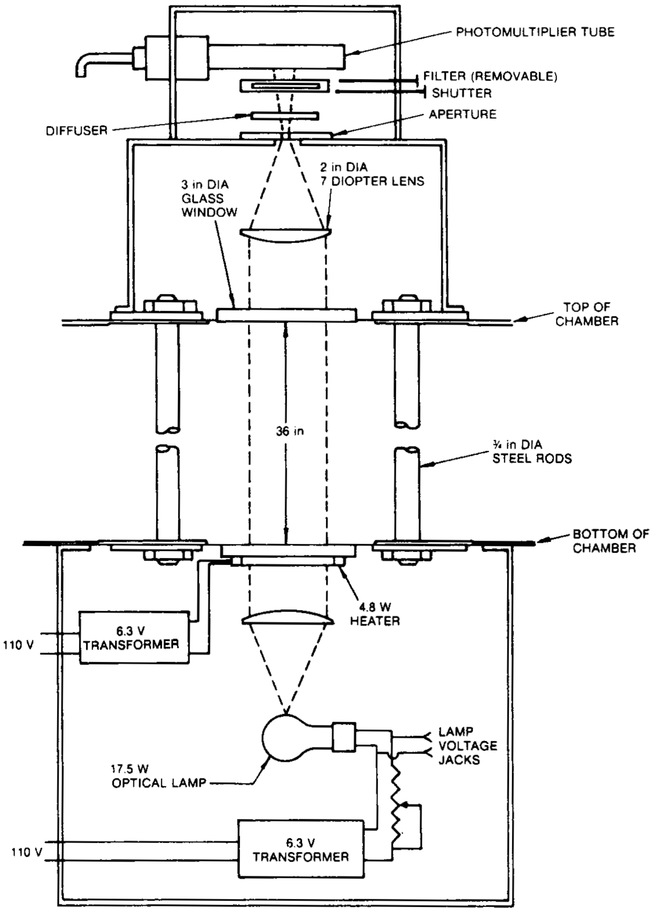


Fig 6
Photometer Details

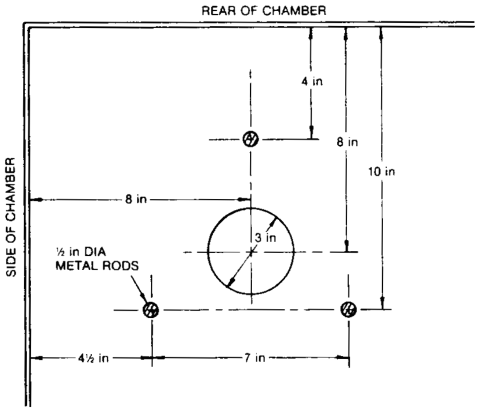


Fig 7
Photometer Location (Plan View)

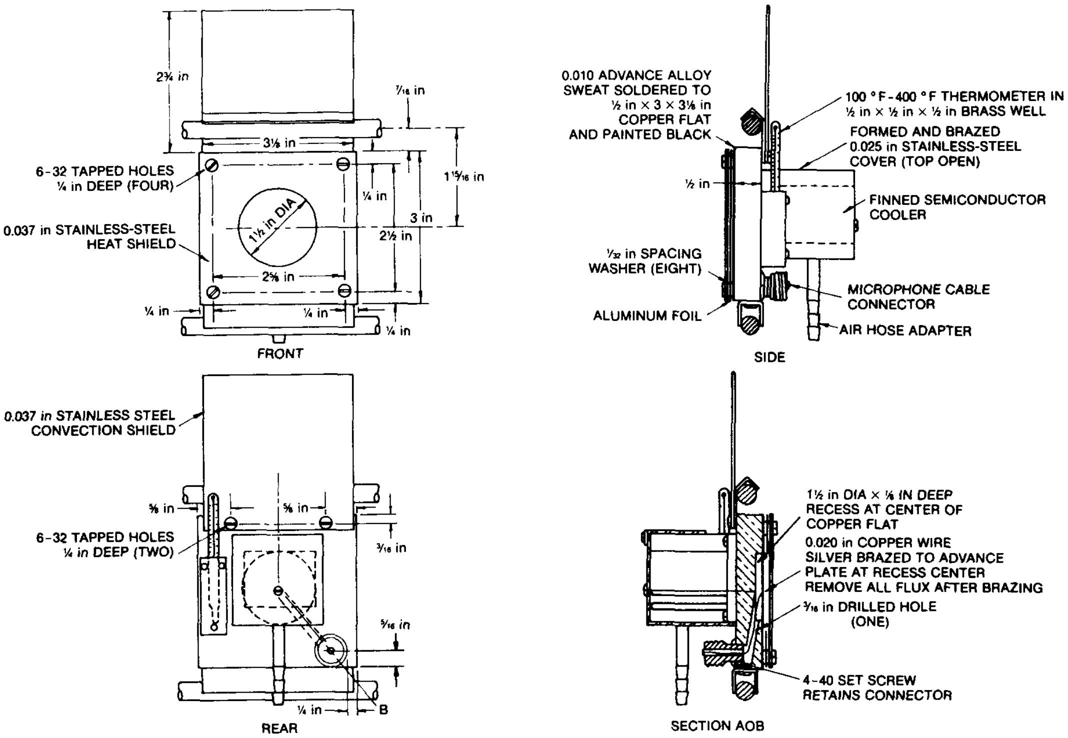


Fig 8
Radiometer Details

of the two horizontal tubes shall be centered ¼ in (6.4 mm) above the holder edge and ¼ in (6.4 mm) away from the specimen surface. Provision shall be made to rotate or move the burner out of position during nonflaming exposures. A premixed air and propane (95% purity or better) test gas shall be used. The air and propane shall be metered by calibrated flow meters and needle valves at 500 cm^3/min for air and 50 cm^3/min for the propane.

3.3 Test Specimens

3.3.1 Size and Orientation

(1) The size of the test specimen shall be 3 in by 3 in ± 0.03 in (76.2 mm by 76.2 mm ± 0.7 mm) by 0.075 in ± 0.005 in (1.91 mm ± 0.13 mm) thick. If specific conditions warrant it, other thicknesses may be tested. These specific conditions should be included in the report.

(2) 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. The highest smoke density value and the test orientation shall be stated.

3.3.2 Specimen Assembly

(1) The specimen shall be representative of the materials or composite and shall be prepared in accordance with recommended application procedures. However, flat sections of the same thickness and composition may be supplied and tested in place of curved, molded, or specialty parts. Substrate or core materials for the test specimens should be the same as those for the intended application.

(2) Finish materials, including 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 its smoke-generating characteristics. To evaluate these effects, supplementary tests performed on a scored (slit) 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.

3.3.3 Specimen Mounting

(1) All specimens shall be covered across the back, along the edges, and over the periphery of the front surface with a single sheet of aluminum foil 0.0015 in ± 0.0005 in (or approximately 0.04 mm) thick. Care shall be taken not to puncture the foil or to 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. In using the modified holder with the trough, a flap of foil should be cut and bent forward at the spout to permit flow from melting specimens.

(2) All specimens shall be backed with a sheet of asbestos millboard. The specimen and its backing shall be secured with the spring and retaining rod. A modified C-shape retaining rod shall be used with specimens from ⅝ in to 1 in (1.6 cm to 2.5 cm) thick. Do not compress flexible specimens below their normal thickness.

(3) It is the intent of this test method to maintain the prescribed exposure conditions on the specimen for the test duration. If the material overflows the trough, the specimen area should be reduced. The reduced specimen should be centrally located in the holder and the reduced area used for calculating the specific optical density.

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

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

3.4 Test Procedure

3.4.1 Ambient Conditions. 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% ± 20% at the time of test.

3.4.2 Cleaning of Chamber. Clean the chamber walls whenever periodic visual inspection indicates the need. An ammoniated spray detergent and soft scouring pads have been found effective. Clean the exposed surfaces of the glass windows separating the photodetector and light source housings from the interior of the chamber, before each test (ethyl alcohol is generally effective). Charred residues on the specimen holder and horizontal rods should be removed to avoid contamination.

3.4.3 Furnace Warm-Up

(1) 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 95 °F ± 4 °F (35 °C ± 2 °C), the chamber is considered to be at steady-state condition and ready for furnace calibration or testing. To increase the chamber wall surface temperature to the stated level under adverse conditions, an auxiliary heater may be used; conversely, to decrease this temperature, the exhaust blower may be used to introduce cooler air from the laboratory. Calibrate the furnace output radiance at periodic intervals according to test experience (normally twice per test day).

(2) A *blank* specimen holder, with the asbestos millboard backing exposed should always be directly in front of the furnace except when displaced to the side by

(a) The specimen holder during a test or

(b) The radiometer during calibration

It should be returned immediately to this position when testing or calibration is completed.

(3) During calibration, the radiometer is 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. With the chamber door closed and inlet vent opened, the compressed-air supply to the radiometer cooler is adjusted to maintain its body temperature at 200 °F ± 5 °F (93 °C ± 3 °C). The autotransformer setting is adjusted so as to obtain the calibrated millivolt output of the radiometer corresponding to a steady-state radiance 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.

(4) The recorder or meter described in 3.2.8 is used to monitor the radiometer output. After the prescribed radiance level has reached steady state, the radiometer is removed from the chamber and replaced with the *blank* specimen holder.

(5) After the system has reached steady-state conditions, adjust the meter, or recorder zero, 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, and adjust the *dark current* reading to zero.

3.4.4 Burner Positioning

(1) For nonflaming exposures, the multiple flamelet burner is removed. For flaming exposures, the burner is positioned across the lower edge of the specimen as described in 3.2.10(1). Check the burner distances relative to the *blank* specimen before fuel adjustment and ignition.

(2) Before positioning the test specimen, flush the chamber, with the door and exhaust inlet vents open, for approximately 2 min, and verify the starting temperature of the chamber, using the procedure described in 3.4.3(1).

3.4.5 Exposing the Specimen

(1) 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. When the photometer indicates smoke, only then should the inlet vent be completely closed.

(2) Record the light transmittance and the corresponding time either as a continuous plot with a multirange recorder, or at sufficient time intervals with a multirange recorder, or at sufficient time intervals with a multirange meter readout. Make and note the necessary full-scale range changes in decade steps.

(3) Observe the increase in chamber pressure with the manometer described in 3.2.9. A regulator 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 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.

(4) Record any observations pertinent to the burning and smoke-generating properties of the material under test, in accordance with 3.6(6) and 3.6(7).

(5) Continue the test until 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 minimum transmittance levels have not been reached during the 20 min exposure. The term *extended exposure* is to be used to identify data developed in tests longer than 20 min in duration.

(6) 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 so as 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.

(7) Extinguish the burner on flaming exposures and start exhausting the chamber within one minute after reaching minimum transmittance. Displace the specimen from the front of the furnace by pushing the *blank* specimen holder with the positioning rod. Continue the exhaust process with the inlet vent open until maximum transmittance is reached. Record this transmittance value as the T_c, *clear beam* reading, which is to be used to correct for deposits on the photometer windows.

3.5 Calculations

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

$$D_s = \frac{V}{LA}\left[\log_{10}\left(\frac{100}{T}\right)\right] = G\left[\log_{10}\left(\frac{100}{T}\right)\right] \qquad \text{(Eq 1)}$$

where
T = light transmittance
A = exposed specimen area
V = volume
L = light path
G = geometrical factor associated with the dimensions of the chamber and specimen

3.5.2 When the neutral density filter has been removed to measure low levels of light transmittance, the specific optical density of the filter shall be added. Determine the value to be added by multiplying G in Eq 1 by the known optical density of the filter.

3.5.3 Calculate the maximum specific optical density D_m, using Eq 1 with a light transmittance corresponding to the minimum level reached during the test. Correct all maximum specific optical density values by subtracting the specific optical density equivalent for soot and other deposits on the photometer windows. As described in 3.4.5(7). the *clear beam* transmittance reading T_c is used to calcualte a specific optical density equivalent D_c, using the same formula but with different subscripts. A corrected maximum specific optical density calculation is expressed as follows:

$$D_m\,(\mathrm{corr}) = D_m - D_c \qquad \text{(Eq 2)}$$

3.5.4 For systems without *dark current* cancellation, a correction must be made for any light transmittance reading T approaching the dark current value T_d. The corrected light transmittance T', is obtained from:

$$T' = 1 - \frac{1 - T}{1 - T_d} \qquad \text{(Eq 3)}$$

and is used for the specific optical density calculations described in 3.5.1 and 3.5.3.

3.5.5 When the test is continued beyond the standard 20 min exposure, all calculations are to be made in accordance with 3.5.1 through 3.5.4 and the results identified as *Extended Exposure.*

3.6 Report. The report shall include

(1) Complete description of the material tested, including type, manufacturer, shape, thickness, or other appropriate dimensions, or a combination of these; weight or density, coloring, etc.

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

(3) Test specimen conditioning procedure.

(4) Number of specimens tested.

(5) Test conditions: type of exposures and exposure period.

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

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

(8) 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.

(9) Test results calculated as described in 3.5 including the average and range on each set of specimens for D_m (corr), D_c, and others if required.

3.7 Precision and Accuracy [5]. For D_m values above 100, the coefficient of variation of measurements on a uniform sample by an individual laboratory may range from 2% to 8%. For D_m values below 100, the estimated standard deviation by an individual laboratory is approximately 10 or less. For measurements among laboratories, the coefficient of variation and standard deviation estimates may be greater by a factor of approximately 1.5.

4. Arapahoe Method

4.1 Summary of Method

(1) A 1½ by ½ in (38.1 mm by 12.7 mm) specimen of thickness between 0.050 in and 0.125 in (1.27 mm and 3.17 mm), and a glass fiber filter 3.5 in (90 mm) in diameter are weighed separately on an analytical balance accurate to at least ± 0.2 mg.

(2) The specimen and filter are positioned in a laboratory test chamber with high-capacity vacuum source. Air is drawn through the test chamber and the filtration system at the rate of 4.5 $\mathrm{ft}^3/\mathrm{min}$ (0.127 $\mathrm{m}^3/\mathrm{min}$). Smoke particulates from the 30 s flaming exposure of the specimen impinge upon the filter. The air flow is allowed to continue for 30 s after ignition flames have been extinguished.

(3) Upon completion of the burn, the sample and filter are removed from the test chamber and weighed upon an analytical balance.

(4) Char is mechanically removed from the burned specimen before weighing it the third and final time.

(5) Smoke and char weights are calculated by difference and expressed as percentages of the total amount of sample burned.

4.2 Test Equipment

4.2.1 Test Apparatus. The smoke test apparatus shall be essentially as shown in Figs 9 and 10 and shall consist of a combustion chamber with ignition source, a particulate filtration system, and a decharring mill.[5]

4.2.2 Combustion Chamber. As shown in Fig 11, the combustion chamber shall be a cylinder 5 in (127 mm) in outer diameter by 7 in (178 mm) high. The walls shall be of type 304 stainless steel, 0.120 in (3.0 mm) thick. Two openings shall be cut

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[5] Smoke Chamber Model 705, as manufactured by Arapahoe.

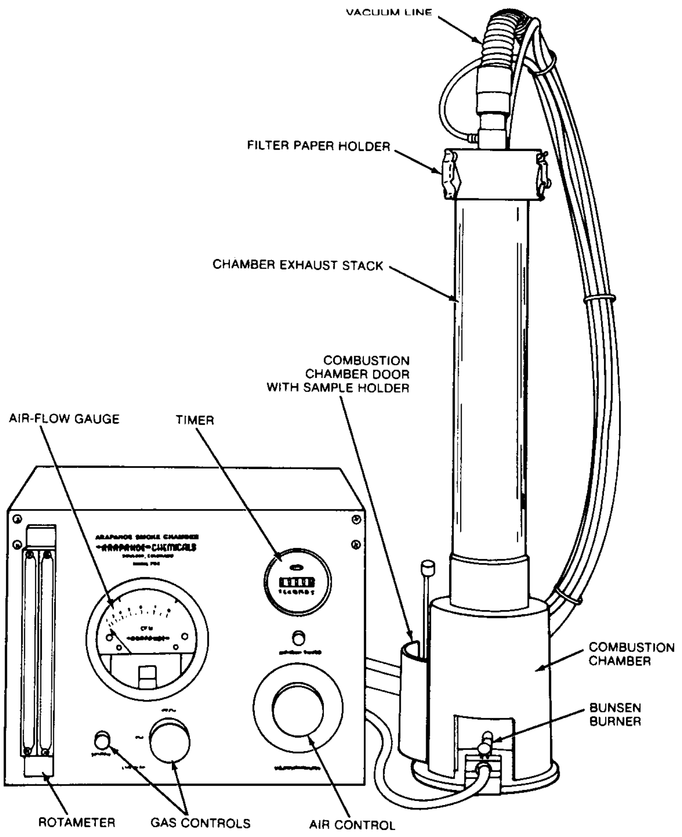


Fig 9
Front View of Instrument

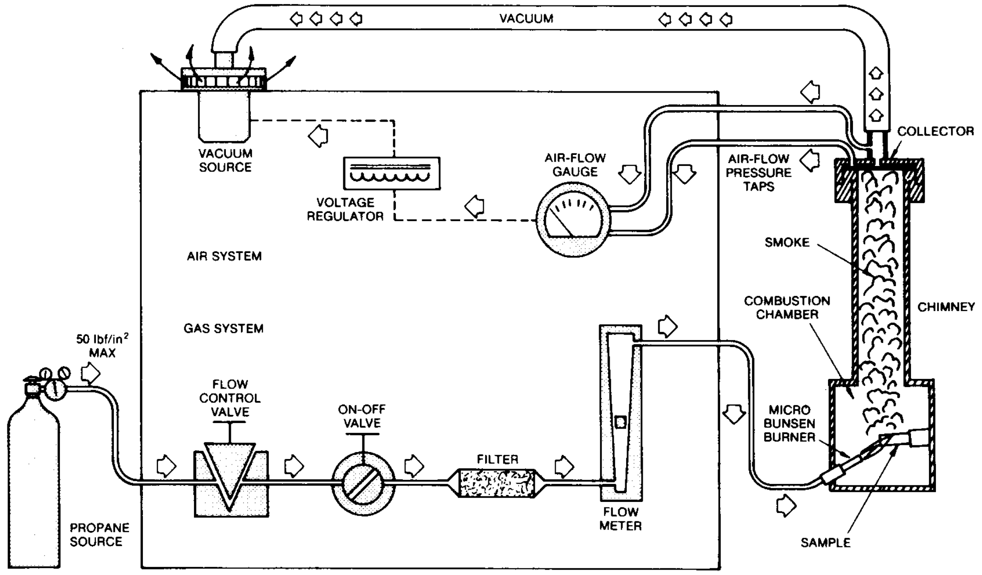


Fig 10
Schematic of Arapahoe Smoke Chamber

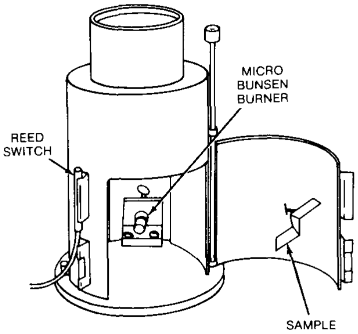


Fig 11
Combustion Chamber

at the bottom of the test chamber at opposite sides of the cylinder. In the front a 2¼ in (57.2 mm) square opening and in the rear a rectangular 3¾ in (95.3 mm) high by 4 in (101.6 mm) wide opening are required. The base of the chamber shall be 6 in (152 mm) in diameter by ¼ in (6.4 mm) thick removable stainless-steel slab. The top of the combustion chamber shall be enclosed with the exception of an exhaust port 3 in (76.2 mm) in diameter with a 2 in (50.8 mm) high collar into which the chamber stack may be inserted. The exhaust port collar shall contain two O-ring seals and shall be machined to a close tolerance so that a tight fit can be maintained with a chimney to prevent leakage of combustion products out of the top of the test chamber.

4.2.3 Ignition Source. A propane micro bunsen burner[6] shall be positioned at a 10° angle above horizontal in the combustion chamber as shown in Figs 12 and 13. The burner orifice shall be 0.010 in (0.254 mm) in diameter and 0.032 in (0.813 mm) long and shall be free from burrs caused by the drilling process. The burner shall be mounted on movable blocks and shall be pointed toward the sample holder inside the combustion chamber. Movable mounting blocks are required to adjust the burner position relative to test specimens held in place by the sample holder in the combustion chamber. Provision should be made to firmly lock the burner mounting blocks in place once the proper spacing relative to the test specimen has been obtained. The micro bunsen burner shall be connected by rubber or plastic tubing to a rotameter capable of measuring up to 9.2 in^3/min (150 cm^3/min) of propane gas with an accuracy of at least 5% of full scale flow. The gas shall be filtered through a 2 μm sintered, stainless-steel

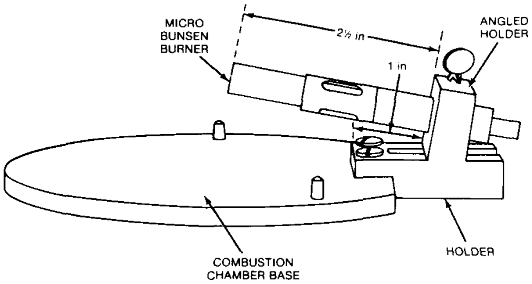
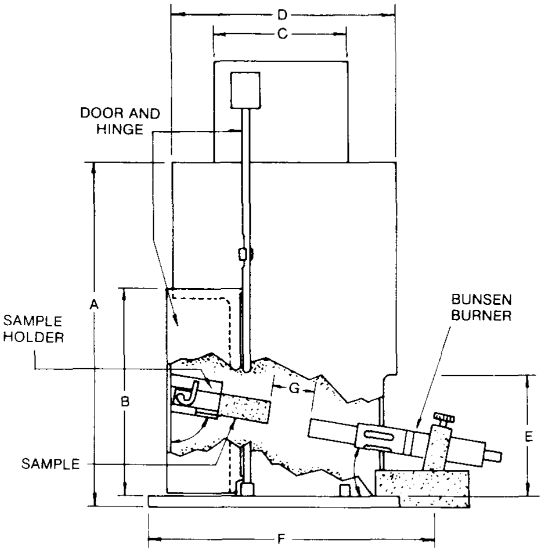


Fig 12
Inner Chamber and Micro Bunsen-Burner Positioning



Dimension Table

	in	cm		in	cm
A	7	17.78	F	6	15.24
B	4.25	10.80	G	0.875	2.22
C	3	7.62	H	80°	—
D	5	12.70	I	10°	—
E	2.25	5.72			

Fig 13
Combustion Chamber Sample Holder and Burner

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[6] Humbolt Model H5815 burner tube with orifice has been found to be particularly suitable for this purpose.

element prior to entering the rotameter. A ball valve shall be upstream of the filter. The valve shall have an orifice size of at least 0.125 in (3.2 mm) with a flow coefficient of 0.40 cv. The ball valve shall have quick operation with one-fourth turn required to completely open or close it. The gas flow to the ball valve shall be controlled by a fine metering valve. The metering valve shall have a 0.031 in (0.787 mm) orifice, and a stem taper of 1° angle with 8 to 12 turns to full open. The flow coefficient through the metering valve shall be 0.004 cv with approximately 0.006 in^3 (0.983 cm^3) of dead space. The valve shall be rated to withstand a pressure of at least 200 lbf/in^2 (1.38 Mpa) at 70 °F (21 °C). Gas flow to the metering valve shall be provided by a constant flow propane source delivering approximately 0.5 lbf/in^2–2.5 lbf/in^2 (0.00345 MPa–0.0173 MPa) of inlet pressure.

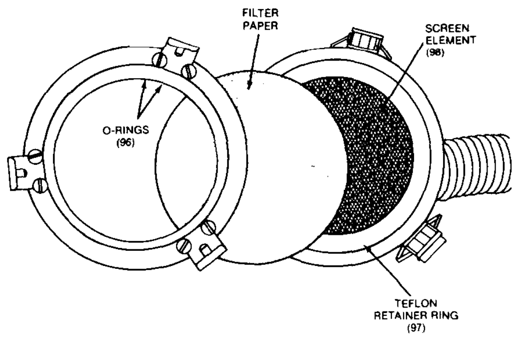

Fig 14
Filter Paper Holder Assembly

4.2.4 Sample Holder. The sample holder shall be attached to a 4¼ in (108 mm) high by 4 in (102 mm) wide removable doorway that covers the rectangular opening at the rear of the test chamber. The sample holder shall be 1.781 in (45.24 mm) above the floor of the combustion chamber and shall be tilted at a 10° angle below horizontal. The holder shall be 1⅛ in (28.58 mm) long by ½ in (12.7 mm) wide by ¾ in (19.1 mm) high with a vertical pin near its midpoint. A spring loaded clip shall be attached to the pin so that specimens can be clamped in place in a fixed and repeatable fashion in the test chamber. As a final check on the sample holder positioning the distance from the end of the propane micro Bunsen-burner barrel to a standard 1½ by ½ in (38.1 mm by 12.7 mm) sample mounted in the combustion chamber should be ⅞ in (22.2 mm). The center of the Bunsen-burner barrel should be in a direct line with an ignition point 1/16 in (1.58 mm) above the lowest point of the exposed edge of the test specimen. The doorway with the sample holder shall have at least two magnetic catches to keep it shut during the test. A magnetic switch that activates a timer accurate to ± 0.5 s when the door is shut, shall be mounted directly opposite the upper catch on the sample holder door.

4.2.5 Chamber Stack. An exhaust stack 18 in (457 mm) high constructed of a thin wall stainless-steel tubing shall be inserted vertically in the collar at the top of the combustion chamber. The tube shall have a wall thickness of approximately 0.069 in (1.75 mm) and have an outer diameter of 3 in (76.2 mm). A 45° chamfer shall be machined on both ends of the tube. The bottom 2 in (50.8 mm) of the stack shall have a diameter of 2.985 in ± 0.003 in (79.82 mm ± 0.08 mm) to allow for easy insertion into the 2 in (50.8 mm) high support collar at the top combustion chamber. The top of the stack shall have an outer diameter of 2.980 in ± 0.003 in (75.69 mm ± 0.08 mm) to facilitate insertion into filtration mechanism of the instrument.

4.2.6 Filtration System. A system for filtration of particulate matter from combustion products withdrawn from the combustion chamber shall be connected to the top of the combustion chamber stack with a snug fit. The filter media shall be a glass fiber pad 3.5 in (90 mm) in diameter and 0.125 in (3.18 mm) thick with a dop[7] efficiency of at least 99.97% for particles 0.3 μm or larger (0.3 m · 10^{-6} m).[8] The filter-paper support system required for good collection shall be a filter holder, a vacuum line, and a high capacity vacuum source.

4.2.6.1 Filter Holder. The filter holder shown in Figs 14 and 15 shall be manufactured from heat- and corrosion-resistant material equal to or better than Type 1 polyvinyl chloride. The filter holder body shall be 4 in (102 mm) in diameter and 1⅛ in (28.6 mm) thick. A cylindrical cavity shall be made in it to hold the filter medium. The filter shall be supported on 200 mesh stainless-

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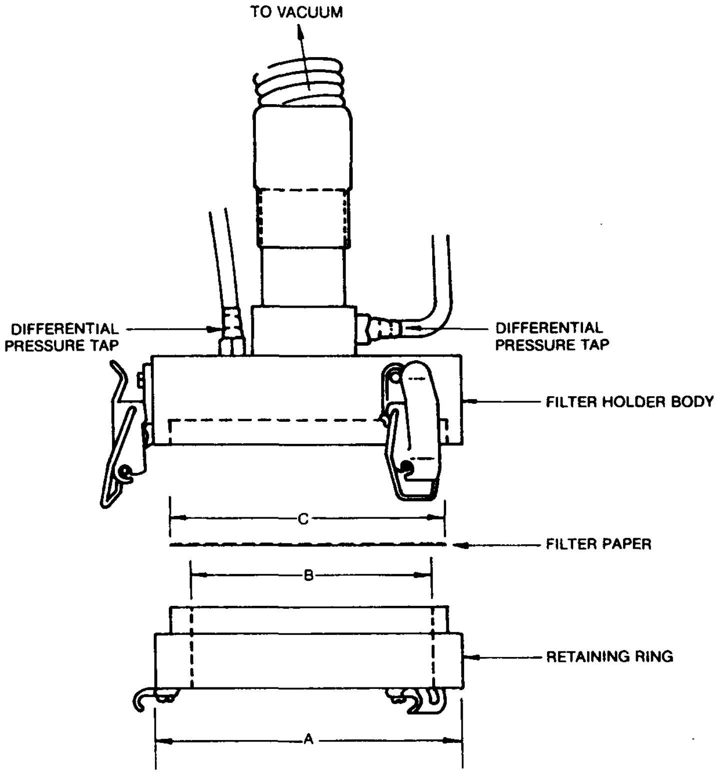
[7] Retention efficiency expressed in percentage of dioctyl phthalate particles of 0.3 μm.

[8] Reeve-Angel number 934-AH or Schleicher and Schuell grade 25 filter papers have been found to be particularly well suited for this purpose.



Dimension Table

	in	cm
A	4	10.16
B	3	7.62
C	3.54	9.0

Fig 15
Filter Holder Assembly

steel cloth, wrapped on perforated 20 gauge stainless-steel sheeting. A Teflon®[9] sealing ring with 2⅞ in (73.0 mm) inside diameter and 32$^{17}/_{32}$ in (89.69 mm) in outside diameter by 0.062 in (1.575 mm) thickness shall be supplied to provide additional seal around the rear edge of the glass-fiber filter media. The Teflon® support ring and the stainless-steel filter-support media shall be permanently mounted in the filter-holder body. Behind the support screen an orifice ½ in (12.7 mm) in diameter by ⅛ in (2.18 mm) thick with serrated hose connectors on either side shall be drilled to obtain pressure drop information required to meter the volumetric flow of combustion products.[10] A removable filter-holder retaining ring shall be supplied to keep the filter media in place and to prevent the bypass of combustion products around it during the test period. The retainer ring shall have an outer diameter of 4 in (101.6 mm) and shall be secured to the filter-holder body by three latches.[11] The filter retainer ring shall have an inner diameter of 3.010 in ± 0.033 in (76.454 mm ± 0.076 mm) to provide a snug fit with O-ring seals at the top of the combustion chamber stack.

4.2.6.2 Vacuum Line. The filter-holder body shall have a hose connection downstream from

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[9] ® Registered Trademark of DuPont Co.

[10] A Dwyer Model 2010 Magnahelix Gauge has been found suitable.

[11] Nielson HC 200 latches perform satisfactorily.

the ½ in (12.7 mm) pressure drop orifice to allow a 1¼ in (31.75 mm) vacuum line 6 ft (1.83 m) long to be connected and held securely in place. At the end of the vacuum hose a restricting orifice ¼ in (6.35 mm) in diameter drilled through a ⅛ in (3.175 mm) thick polyvinyl chloride (pvc) plate shall be connected. The plate shall be affixed to the inlet of the high capacity vacuum source.

4.2.6.3 Vacuum Source. The suction source for the filtration system shall be a 1 hp bypass vacuum pump capable of maintaining at least 80 in (2 m) of water with sealed vacuum. The two-stage vacuum system shall be capable of pulling at least 4.5 ft^3/min (0.127 m^3/min) of air through the ½ in (12.7 mm) metering orifice and the ¼ in (6.35 mm) restrictor orifice when operated at 70%-90% of full power from a 110 V, 60 Hz power supply. The fan blades and housing on the motor shall preferably be coated with epoxy to prevent corrosion. The vacuum pump shall be connected to a rheostat to control its speed.

4.2.7 Decharring Mill. A roll mill shall be provided to grind char from burned test specimens. The mill shall be tilted upward at an angle of 30° and shall have the capacity to turn at least two tumblers at a speed of 60 r/min.

(1) The tumblers shall be rubber cylinders 4 in (101 mm) in inside diameter and 4 in (101 mm) in height with removable tops.

(2) Each tumbler barrel shall be filled with 300 g of 20 to 30 mesh sand that meets the requirements of ASTM C190-1985 [1]. Ottawa sand has been found to be suitable for this purpose.

(3) A wire brush with 10 gauge bristles or equivalent shall be provided for decharring samples by hand.

4.2.8 Auxiliary Equipment

(1) A laboratory fume hood, a space at least 2 ft (0.6 m) wide, 2 ft (0.6 m) deep, and 3 ft (0.9 m) high with good ventilation shall be provided.

(2) A laboratory analytical balance with at least 10 g capacity and ± 0.2 mg accuracy shall be provided.

(3) A propane source with an adjustable regulator to deliver at least 9.3 in^3/min (150 cm^3/min) of 95% pure propane gas at no more than 2½ lbf/in^2 (17.2 kPa) or no less than ½ lbf/in^2 (3.4 kPa) of outlet pressure shall be provided.

4.3 Precautions

(1) All connections in the ignition system shall be checked for leakage of propane gas.

(2) The flow of propane gas to the micro Bunsen burner in the combustion chamber shall not be started unless air is flowing through the filtration system.

4.4 Sampling

(1) The test specimen shall be a single homogeneous material as a standard size sample in slab configuration cut in a manner that produces a surface free from projecting fibers, chips, and ridges.

(2) Test specimens of rigid polymeric materials shall be cut to the required dimensions on a band saw with the metal cutting blade having between 14 and 18 teeth per inch (5.5 and 7.1 teeth per cm). Test specimens of flexible materials shall be cut to the required dimensions with a sharp, single-edge razor blade or similar cutting device.

4.5 Test Specimen and Sample

(1) The standard specimen shall be 1.5 in ± 0.025 in (38.1 mm ± 0.64 mm) long by 0.5 in ± 0.075 in (12.7 mm ± 1.9 mm) wide by 0.125 in (3.2 mm) thick. The maximum specimen thickness allowed is 0.188 in (4.78 mm) and the minimum is 0.050 in (1.27 mm). Thicknesses other than 0.125 in (3.2 mm) may be used if the size is reported and all other test specimens in the sample series are of the same dimensions.

(2) The test sample shall consist of a minimum of 4 and a maximum of 6 specimens.

(3) Each test specimen shall be numbered with indelible ink on one end for reference purposes.

4.6 Conditioning

(1) For those tests where conditioning is required ASTM D618-1961 (81) [2], Procedure A, shall be followed. The test specimens shall be conditioned at 23 °C ± 2 °C (73.4 °F ± 3.6 °F) and 50% ± 5% relative humidity for not less than 40 h. In cases of disagreement, the tolerances shall be ± 1 °C (± 1.8 °F) and ± 2% relative humidity.

(2) Tests shall be conducted in a standard laboratory atmosphere of 23 °C ± 2 °C (73.4 °F ± 3.6 °F) and 50% ± 5% relative humidity, unless otherwise specified in the test methods or in this guide. In cases of disagreement, the tolerances shall be ± 1 °C (± 1.8 °F) and ± 2% relative humidity.

(3) Tests shall be conducted in a laboratory fume hood for at least 3 ft (0.9 m) high by 2 ft (0.6 m) wide by 2 ft (0.6 m) deep with a face velocity of at least 50 ft/min (15.2 m/min).

4.7 Preparation of Apparatus

(1) The combustion chamber and stack shall be cleaned with soap and water and thoroughly dried on a daily basis or after each series of 60 tests.

(2) The sand in the tumblers shall be replaced with clean material after it has been used to dechar a maximum of 36 test specimens.

4.8 Procedure

(1) Weigh a test specimen and the glass-fiber filter paper separately on an analytical balance accurate to at least ± 0.2 mg. Record the data, handle the specimen, and filter with forceps.

(2) Install the filter in the holder assembly at the top of the combustion chamber stack. The smooth side of the filter should be against the support screen.

(3) Fasten the retainer ring clamps and slide the filter paper holder into place at the top of the chimney on the combustion chamber.

(4) Install the test specimen in the combustion chamber by removing the rear door and sliding the numbered end of the sample into the spring loaded holder clip. The edges of the specimen must be against the edges of the holder to ensure proper positioning during combustion. The sample shall be positioned securely in the holder clip with the 1½ in (38.1 mm) length on the horizontal axis and the ½ in (12.7 mm) height on the vertical axis. The rear and top edges of the specimen shall be in contact with the sample holder to ensure fixed and repeatable positioning of the specimen relative to the ignition source.

(5) Replace the combustion chamber door at the rear of the instrument leaving the door open.

(6) Set the instrument timer to 0 s.

(7) Start the air flow through the combustion chamber and the filtration system and adjust to a reading of 4.5 ft^3/min (0.127 m^3/min) on the Magnahelix Gauge by turning the air-flow control knob to any increment between 70% and 90% of full scale.

(8) Open the ball valve in the ignition system to allow propane gas to flow. Adjust the flow with the micro metering valve to 5.5 in^3/min (90 cm^3/min) as measured on the rotameter.

(9) Ignite the propane micro Bunsen burner through the front doorway in the combustion chamber.

(10) Close the combustion chamber door to ignite the specimen, start the timer, and begin the test.

(11) Allow the specimen to burn for 30 s in front of the propane micro Bunsen burner before closing the ball valve and extinguishing the ignition flames. If the specimen continues to flame or smolder after ignition flames have been extinguished a jet of nitrogen may be necessary to prevent further combustion of the specimen.

(12) At the end of 60 s the air flow through the combustion chamber and filtration system shall be stopped.

(13) Remove the burned specimen and the glass-fiber filter from the instrument and weigh each on an analytical balance. Record the data together with any observations of unusual characteristics in the combustion of the specimen.

(14) Place the burned specimen in the tumbler containing 300 g of sand and roll for 45 min to remove char. A maximum of 6 samples shall be in a tumbler. Should insufficient char removal occur in the tumbler, the sample may be manually decharred with a brush having 10 gauge wire bristles.

(15) Remove the decharred sample from the tumbler, clean thoroughly with a soft brush, a soft cloth, or a stream of nitrogen or air.

(16) Weigh the clean, decharred sample on an analytical balance and record the data.

(17) Samples and filters may now be discarded.

4.9 Calculation of Results

(1) Discard the data in which obvious procedural errors were made, such as improper function of the test equipment, torn filter papers, or lost char from a test specimen.

(2) Determine the total amount burned by subtracting the weight of the decharred specimen from its initial weight. Record the data.

(3) Determine the amount of smoke collected by subtracting the initial filter weight from the final weight of the filter with smoke. Record the data.

(4) Determine the amount of char by subtracting the weight of the decharred specimen from the burned specimen weight. Record the data.

(5) Divide the weight of the smoke and the char by the total amount burned and express as percentages rounded to the nearest 0.1%.

(6) Determine the mean and the standard deviation for the total amount burned, the percentage of smoke, and the percentage of char for each group of test specimens.

4.10 Report. The report shall include

(1) Identification of the materials

(2) The dimensions of the specimens

(3) The mean and standard deviation for the smoke percentage

(4) The mean and standard deviation for the char percentage and the total amount burned may be reported for information purposes

(5) Observations on the behavior of the material during combustion

(6) The details of any departure from the specification of this test method.

4.11 Precision and Accuracy

4.11.1 The following precision criteria shall be used to judge the acceptability of the smoke data percentage:

(1) *Repeatability:* Two individual averages of the smoke data from five specimens as determined by a single operator in one laboratory shall be considered similar (at 95% confidence level) unless they differ by more than 5% absolute.

(2) *Reproducibility:* Two individual averages of the data from five specimens as determined by different laboratories shall be considered similar (at 95% confidence level) unless they differ by more than 23% absolute.

4.11.2 The following accuracy criteria shall be used to judge the acceptability of the total amount burned and the char data percentage that has been included in the test report for information purposes.

(1) The coefficient of variation for the mean char value from a series of six test specimens from a single operator within one laboratory should be less than 10%.

(2) The coefficient of variation for the mean total amount burned value from a series of six test specimens from a single operator in one laboratory should be less than 20%.

Appendix A

(This Appendix is not a part of ANSI/IEEE Std 816-1987, IEEE Guide for Determining the Smoke Generation of Solid Materials Used for Insulations and Coverings of Electric Wire and Cable, but is included for information only.)

NBS Method

A1 Calibration of Test Equipment

A1.1 Photometric System

(1) Calibration of the photometer is checked by interrupting the light beam with calibrated neutral density filters. The filters should cover the full range of the instrument. Optical density values measured by the photometer shall be within ± 3% of the calibrated values.

(2) Shifts in dark current levels between tests, excessive zero shifts during test, or lack of calibration indicates the need for inspection of the photometer system.

(3) The supplementary filter used to extend the measuring range of the photometer shall have an optical density to be known within ± 3%.

A1.2 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 measuring its electrical output as a function of the radiance level. The radiance level is determined calorimetrically by measuring the rate of temperature rise of a blackened thin copper disk of known weight, area (1½ in [38.1 mm] diameter), specific heat, and absorptivity in place of the radiometer. The measured millivolt output of the radiometer, at a body temperature of 200 °F (93 °C), corresponding to a radiance level of 2.2 ± 0.04 Btu/(s·ft^2) [2.5 ± 0.05 W/cm^2] is used to establish the furnace control settings discussed in 3.4.3(1) and 3.4.3(3).

A1.3 Chamber Pressure Manometer—Leakage-Rate Test. For purposes of standardization, periodically conduct a leakage-rate test using the manometer and tubing described in 3.2.9. Pressurize the chamber to 3 in (approximately 76 mm) of water by introducing compressed air through a gas sampling hole in the top. With a stop watch, time the decrease in pressure from 3 in to 2 in (approximately 76 mm to 50 mm) of water. This time should not be less than 5.0 min.

A1.4 Standard Smoke Generating Materials. For checking operational and procedural details of the equipment and method described herein, two standard materials may be used. Under nonflaming conditions, a single layer of nominal 0.030 in (approximately 0.76 mm) thick alpha-cellulose (cotton linters) paper should provide repeatable maximum specific-optical-density values of 170 ± 10; under flaming conditions, a 0.032 in (0.81 mm) thick, plastic sheet should provide repeatable maximum specific-optical-density values of 455 ± 15. These reference samples are designated SRM 1006-1983, Smoke Density, Nonflame (Cellulose) and SRM 1007-1976, Smoke Density, Flame (ABS Plastics).[12]

Use of these standard materials does not obviate the need for following the calibration and standardization procedure outlined in this standard.

A2 Construction Details

A2.1 Radiant Heat Furnace. The furnace shall consist of a coiled wire or other suitable electrical heating element (525 W or greater) mounted vertically in a horizontal ceramic tube 3 in (76.2 mm) id by 3⅜ in (85.7 mm) od by 1⅝ in (41.3 mm) long. The tube is bored out at one end to 3$\frac{1}{32}$ in (77.0 mm) id and to a depth of ⅝ in (15.9 mm) to accommodate the heating element. A $\frac{1}{16}$ in (1.6 mm) asbestos paper gasket and two stainless-steel reflectors are mounted behind the heating element. A ⅜ in (9.5 mm) asbestos millboard disc, provided with ventilation and lead wire holes, shall be positioned behind the heating

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[12] These references are available from the Office of the National Bureau of Standards, Standard Reference Material, Room B 311, Chemistry Building, Gaithersburg, MD 20899.

element and used to center the assembly with respect to the front ⅜ in (9.5 mm) asbestos millboard ring by means of a 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) od by 0.083 in (2.1 mm) wall by 4⅛ in (10.5 cm) long stainless-steel tube. Two additional ⅜ in (9.5 mm) asbestos board spacing rings and a rear cover of ⅜ in (9.5 mm) asbestos board shall complete the furnace. The furnace is to 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 shall be approximately 7¾ in (195 mm) above the chamber floor.

A2.2 Specimen Holder. The specimen holder with trough 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 to provide a 1½ in (38.1 mm) depth, and to expose a 2$^{9}/_{16}$ by 2$^{9}/_{16}$ in (65.1 mm by 65.1 mm) specimen area. As described in 3.2.4, the holder shall have top and bottom guides to permit accurate centering of the exposed specimen area in relation to the furnace opening. A 3 in by 3 in (76.2 mm by 76.2 mm) sheet of ½ in (12.7 mm) asbestos millboard, having a nominal density of 50 lb/ft^3 ± 10 lb/ft^3 (0.85 g/cm^3 ± 0.17 g/cm^3), shall be used to back the specimen. A spring bent from 0.010 in (approximately 0.25 mm) thick phosphor bronze 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

(1) The framework as shown in Fig 5 shall have welded to it a 5 in (12.7 cm) 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 4.1(2). This support tube shall have a provision to accurately align the furnace opening so that it is 1½ in (38.1 mm) away from, parallel to, and centered with respect to the exposed specimen area. Three tapped holes with screws equidistantly positioned around the furnace support tube, or one screw at the top of the support in conjunction with two adjustable (vertically along the support tube) metal guide strips mounted horizontally inside the tube, shall provide adequate alignment.

(2) 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 A2.2. 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

(1) The photometric system shall consist of a tungsten-filament light source (Type 1630, 6.5 V lamp, maintained at 4 V ± 0.2 V), and photodetector (Type 931 VA), oriented vertically to reduce variations in measurement brought about by stratification of the smoke generated by the specimens under test. The system shall be shown as in Figs 6 and 7. The window in the chamber floor through which the light beam passes shall be 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 shall have a path length of 36 in ± ⅛ in (914 mm ± 3.2 mm) and a sensing cross section of 1½ in ± ⅛ in (38.1 mm ± 3.2 mm) diameter. The approximately circular light *spot* shall be centered entirely within the sensing area of the detector. A typical photomultiplier photometer system will require a high-voltage, direct-current 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 up to 6.0, corresponding to transmittance values of 0.0001% of the incident light [see A1.1(1)].

(2) The two optical platforms and their housings shall be kept in alignment by 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

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

(2) The circular receiving surface of the radiometer shall be spray-coated with an infrared-absorbing black paint containing silicone.

The radiometer shall be calibrated calorimetrically in accordance with the procedure summarized in A1.2.

A2.6 Chamber Wall Thermocouple. A thermocouple shall be mounted with its junction secured to the geometric center of the inner rear wall panel of the chamber using an insulating disc cover and epoxy cement.

A2.7 Burner

(1) The six-tube, multiple-flame burner is shown, with construction details, in Fig 4.

(2) The vertical tubes of the six-tube burner shall be made from ⅛ in (3.2 mm) outside diameter by 0.031 in (0.8 mm) thick wall stainless-steel tubing. Two of the tubes are bent 180° into the trough, two others are bent 135° from the vertical, and the remaining two tubes are bent 90° from the vertical.

(3) The tips of the tubes should be swaged to reduce the opening diameter to 0.055 in (1.4 mm).

(4) The horizontal manifold section of the burner consists of ¼ in (6.4 mm) od by 0.035 in (0.9 mm) wall stainless-steel tubing. The other end is attached to a fitting in the chamber floor.

A2.8 Pressure Regulator. An open, water-filled bottle and a length of flexible tubing makes a simple pressure regulator for the chamber. One end of the tubing is connected to a sampling port in the top of the chamber and the other end is inserted 4 in (10 mm) below the water surface in the bottle. The bottle is located at the same level as the floor of the chamber.