



Designation: D5537 – 23

Standard Test Method for Heat Release, Flame Spread, Smoke Obscuration, and Mass Loss Testing of Insulating Materials Contained in Electrical or Optical Fiber Cables When Burning in a Vertical Cable Tray Configuration¹

This standard is issued under the fixed designation D5537; 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.

1. Scope*

1.1 This is a fire-test-response standard.

1.2 This test method provides a means to measure the heat released and smoke obscuration by burning the electrical insulating materials contained in electrical or optical fiber cables when the cable specimens, excluding accessories, are subjected to a specified flaming ignition source and burn freely under well ventilated conditions. Flame propagation cable damage, by char length, and mass loss are also measured.

1.3 This test method provides two different protocols for exposing the materials, when made into cable specimens, to an ignition source (approximately 20 kW), for a 20 min test duration. Use it to determine the heat release, smoke release, flame propagation and mass loss characteristics of the materials contained in single and multiconductor electrical or optical fiber cables.

1.4 This test method does not provide information on the fire performance of materials insulating electrical or optical fiber cables in fire conditions other than the ones specifically used in this test method nor does it measure the contribution of the materials in those cables to a developing fire condition.

1.5 Data describing the burning behavior from ignition to the end of the test are obtained.

1.6 This test equipment is suitable for measuring the concentrations of certain toxic gas species in the combustion gases (see [Appendix X4](#)).

1.7 The values stated in SI units are to be regarded as standard (see [IEEE/ASTM SI-10](#)). The values given in parentheses are mathematical conversions to inch-pound units that are provided for information only and are not considered standard.

¹ This test method is under the jurisdiction of ASTM Committee D09 on Electrical and Electronic Insulating Materials and is the direct responsibility of Subcommittee D09.17 on Fire and Thermal Properties.

Current edition approved Feb. 1, 2023. Published February 2023. Originally approved in 1994. Last previous edition approved in 2018 as D5537 – 18. DOI: 10.1520/D5537-23.

1.8 *This standard measures and describes the response of materials, products, or assemblies to heat and flame under controlled conditions, but does not by itself incorporate all factors required for fire hazard or fire risk assessment of the materials, products or assemblies under actual fire conditions*

1.9 *Fire testing is inherently hazardous. Adequate safeguards for personnel and property shall be employed in conducting these tests.*

1.10 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.11 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*²

- D1711 Terminology Relating to Electrical Insulation
- D5424 Test Method for Smoke Obscuration of Insulating Materials Contained in Electrical or Optical Fiber Cables When Burning in a Vertical Cable Tray Configuration
- E84 Test Method for Surface Burning Characteristics of Building Materials
- E176 Terminology of Fire Standards
- E603 Guide for Room Fire Experiments
- E800 Guide for Measurement of Gases Present or Generated During Fires
- E1354 Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter

² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

*A Summary of Changes section appears at the end of this standard

E1537 Test Method for Fire Testing of Upholstered Furniture

E2067 Practice for Full-Scale Oxygen Consumption Calorimetry Fire Tests

E3020 Practice for Ignition Sources

IEEE/ASTM SI-10 International System of Units (SI), The Modernized Metric System

2.2 *NFPA Standards:*³

NFPA 70 National Electrical Code

NFPA 265 Standard Methods of Fire Tests for Evaluating Room Fire Growth Contribution of Textile Wall Coverings

NFPA 286 Standard Methods of Fire Tests for Evaluating Contribution of Wall and Ceiling Interior Finish to Room Fire Growth

NFPA 289 Standard Method of Fire Test for Individual Fuel Packages

2.3 *Underwriters Laboratories Standards:*⁴

UL 1581 Reference Standard for Electrical Wires, Cables, and Flexible Cords

UL 1685 Vertical Tray Fire Propagation and Smoke Release Test for Electrical and Optical Fiber Cables

UL 2556 Wire and Cable Test Methods

2.4 *Canadian Standards Association Standard:*⁵

CSA FT4, Vertical Flame Tests: Cables in Cable Trays, Section 4.11.4 in Standard C 22.2 No. 0.3, Test Methods for Electrical Wires and Cables

2.5 *IEEE Standard:*⁶

IEEE 1202 Standard for Flame Testing of Cables for Use in Cable Tray in Industrial and Commercial Occupancies

2.6 *ISO Standard:*⁷

ISO 9705 Fire Tests—Full Scale Room Test for Surface Products

ISO 13943 Fire Safety—Vocabulary

3.2.3 *smoke obscuration, n*—reduction of light transmission by smoke, as measured by light attenuation.

3.2.4 *specimen, n*—the individual length of cable, or cable bundle, to be placed in the cable tray, which is representative of the product to be tested.

4. Summary of Test Method

4.1 This fire-test-response standard determines a number of fire-test-response characteristics associated with burning the materials insulating electrical or optical fiber cables, made into cable specimens, and located in a vertical cable tray and ignited with a propane gas burner. The main fire properties measured are the rate of heat release and its amount. Associated with these measurements, the test procedure also determines flame propagation cable damage (by char length), smoke obscuration, and mass loss of specimen. The apparatus described in this test method is also suitable for measuring rates and concentrations of gaseous combustion products released.

4.2 The vertical cable tray that holds the specimen is located in an enclosure of specified dimensions.

4.3 A hood, connected to a duct is located above the fire enclosure. Heat and gas release analysis instrumentation is placed in the duct. Smoke release instrumentation (optional) is also placed in the duct.

4.4 Two different test procedures are specified, which differ in the burner used and in the electrical or optical fiber cable loading. These reflect details of four existing test methods: UL 1581 (vertical tray flammability test, protocol A) and CSA Standard C 22.2 No. 0.3 (FT4 vertical tray flammability test) or IEEE 1202 (protocol B) and UL 1685 and Test Method **D5424** (both protocols, for smoke obscuration only). Both test procedures described in detail in this test method are also identified in UL 2556.

4.5 Information specific to the individual protocols is found in **7.7**, **7.9**, and **11.1**.

5. Significance and Use

5.1 This test method provides a means to measure a variety of fire-test-response characteristics associated with heat and smoke release and resulting from burning the materials insulating electrical or optical fiber cables, when made into cables and installed on a vertical cable tray. The specimens are allowed to burn freely under well ventilated conditions after ignition by means of a propane gas burner. The ignition source used in this test method is also described as a premixed flame flaming ignition source in Practice **E3020**, which contains an exhaustive compilation of ignition sources.

5.2 The rate of heat release often serves as an indication of the intensity of the fire generated. General considerations of the importance of heat release rate are discussed in **Appendix X1** and considerations for heat release calculations are in **Appendix X2**.

5.3 Other fire-test-response characteristics that are measurable by this test method are useful to make decisions on fire safety. The test method is also used for measuring smoke obscuration. The apparatus described here is also useful to

3. Terminology

3.1 For definitions of terms used in this test method and associated with fire issues refer to Terminology **E176** and ISO 13943. In case of conflict, the terminology in Terminology **E176** shall prevail. For definitions of terms used in this test method and associated with electrical insulation refer to Terminology **D1711**.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *heat release rate, n*—the heat evolved from the specimen, per unit of time.

3.2.2 *sample, n*—an amount of the cable type and construction to be tested, which is representative of the product for test.

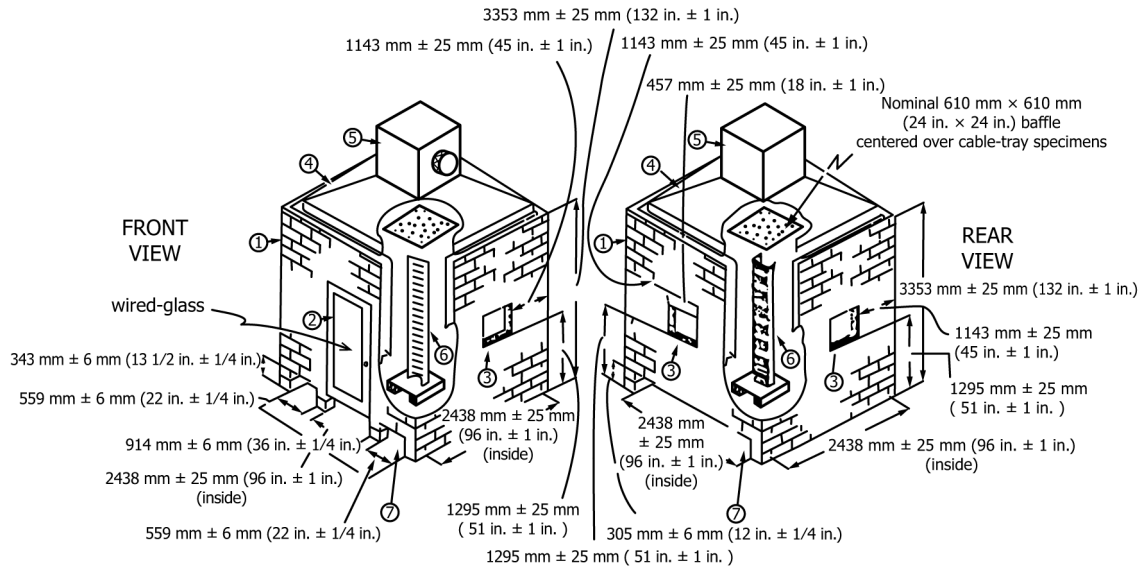
³ Available from National Fire Protection Association (NFPA), 1 Batterymarch Park, Quincy, MA 02169-7471, <http://www.nfpa.org>.

⁴ Available from Underwriters Laboratories (UL), 333 Pfingsten Rd., Northbrook, IL 60062-2096, <http://www.ul.com>.

⁵ Available from Canadian Standards Association (CSA), 5060 Spectrum Way, Mississauga, ON L4W 5N6, Canada, <http://www.csa.ca>.

⁶ Available from Institute of Electrical and Electronics Engineers, Inc. (IEEE), 445 Hoes Ln., P.O. Box 1331, Piscataway, NJ 08854-1331, <http://www.ieee.org>.

⁷ Available from International Organization for Standardization (ISO), 1, ch. de la Voie-Creuse, Case postale 56, CH-1211, Geneva 20, Switzerland, <http://www.iso.ch>.



- (1) Enclosure: an acceptable construction consists of concrete masonry blocks, laid up with mortar, nominally 203 mm high by 406 mm wide by 152 mm thick (8 in. by 16 in. by 6 in.).
- (2) Wired-glass door, for access and observation. The overall size of the door is 2.1 m high and 0.9 m wide (84 in. by 36 in.).
- (3) Steel-framed wired-glass observation windows, 457 mm (18 in.) per side (optional).
- (4) Truncated-pyramid stainless steel hood, with each side sloped 40°.
- (5) Cubical collection box, 914 mm (36 in.) per side, with exhaust duct centered on one side.
- (6) Cable tray, mounted vertically in the center of the enclosure. Tray base (stand) is optional.
- (7) Air intake openings.

FIG. 1 Cable Test Enclosure

measure gaseous components of smoke; the most important gaseous components of smoke are the carbon oxides, present in all fires. The carbon oxides are major indicators of the completeness of combustion and are often used as part of fire hazard assessment calculations and to improve the accuracy of heat release measurements.

5.4 Test Limitations:

5.4.1 The fire-test-response characteristics measured in this test are a representation of the manner in which the specimens tested behave under certain specific conditions. Do not assume they are representative of a generic fire performance of the materials tested when made into cables of the construction under consideration.

5.4.2 In particular, it is unlikely that this test is an adequate representation of the fire behavior of cables in confined spaces, without abundant circulation of air.

5.4.3 This is an intermediate-scale test, and the predictability of its results to large scale fires has not been determined. Some information exists to suggest validation with regard to some large-scale scenarios.

6. Test Specimens

6.1 Use multiple lengths of electrical or optical fiber cable as test specimens.

6.2 The mounting of the specimen on the cable tray is specified in 7.9.

7. Apparatus

7.1 Enclosure:

7.1.1 The enclosure in which the specimen is tested is shown in Fig. 1.

7.1.2 The enclosure has floor dimensions of 2.44 m ± 25 mm by 2.44 m ± 25 mm, with a height of 3.35 m ± 25 mm (8 ft ± 1 in. by 8 ft ± 1 in. by 11 ft ± 1 in. high). On top of the walls there is a pyramidal collection hood with a collection box.

7.1.2.1 Other enclosure sizes, such as 2.4 m by 2.4 m by 2.4 m (8 ft by 8 ft by 8 ft) or the 3 m cube are permitted, provided that the internal volume of the enclosure, exclusive of the pyramidal hood, ranges between 14.5 m³ (512 ft³) and 36 m³ (1272 ft³), the floor area ranges between 6 m² (64 ft²) and 9 m² (97 ft²), and the maximum air movement within the enclosure complies with 7.1.12 (Note 1).

NOTE 1—There is, as yet, not enough information as to the equivalence on smoke release between the various facilities. Further work needs to be done to confirm this.

7.1.2.2 In case of disputes, the referee method is the tests conducted using the enclosure in 7.1.2.

7.1.3 Walls—The maximum conductive heat flux loss of the walls of the structure is 6.8 W/(m²K) (30 Btu/h-ft²), based upon an inside wall temperature of 38 °C (100 °F) and an outside air temperature of 24 °C (75 °F). Paint the interior surface of the walls flat black. Any materials of construction that meet the preceding requirements are acceptable. Two examples of acceptable construction materials are nominally 152 mm (6 in.) thick concrete masonry blocks (density: 1700 kg m⁻³ (106 lb ft⁻³) and thermal conductivity nominally $k = 1.75 \text{ W/(mK)}$, at 21 °C; 12.13 Btu in./ft² h°F, at 70 °F) or

nominally 13 mm (0.5 in.) gypsum board, with 89 mm ± 6 mm (3.5 in. ± 0.25 in.) of standard fiberglass insulation, with an R value of 1.94 m² K/W (which corresponds in practical units to an R value of 11 hft² °F/Btu). Windows for observation of the fire test are allowed in the walls; ensure that the total area of the windows does not exceed 1.86 m² (20 ft²).

7.1.3.1 Select materials of construction which can withstand the high temperatures and presence of open flame within the test enclosure and duct.

7.1.4 Provide air intakes at the base of two opposite walls, one of which contains the access door. Ensure that the total cross sectional area of the air intakes is 1.45 m² ± 0.03 m² (2250 in.² ± 50 in.²), and that the intake areas are divided approximately equally. Fig. 1 shows dimensions for the air intakes installed in the walls. Air intakes are not permitted in either of the other two walls.

7.1.5 Construct a door with wired glass and locate it as shown in Fig. 1. The door is 900 mm ± 25 mm wide and 2100 mm ± 25 mm high (35 in. ± 1 in. by 83 in. ± 1 in.), with an overall conductive heat flux loss no greater than that of the walls, that is, 6.8 W/(m² K) (30 Btu/h-ft²). A steel framed wired glass door will meet these requirements. Adequately seal the sides and top of the door to prevent drafts.

7.1.6 Construct a truncated pyramid stainless steel hood, formed as shown in Fig. 1, and locate it on top of the enclosure walls. Make the slope on each side of the hood 40°. Form a seal between the hood and the walls; a compressible inorganic batting as gasket is suitable.

7.1.7 Insulate the exterior of the hood to make an overall conductive heat loss no greater than that of the walls.

7.1.8 Locate a cubical stainless steel collection box, 910 mm ± 25 mm (36 in. ± 1 in.), on a side on top of the exhaust hood, with a nominal 410 mm ± 25 mm (16 in. ± 1 in.) diameter stainless steel pipe exhaust duct centered in one side.

7.1.9 Install the exhaust duct horizontally and connect it to the plenum of the hood.

7.1.10 Construct a square 610 mm ± 25 mm (24 in. ± 1 in.) baffle, centered over the cable tray. An acceptable height is 300 mm to 400 mm (12 in. to 15 in.) above the tray.

7.1.11 Construct a collection-exhaust system, as explained in 7.2 and Annex A2.

7.1.12 Ensure that the maximum air movement within the enclosure, with only the intake and exhaust openings open, the exhaust fan on, and the burner off, does not exceed 1 m s⁻¹ (3.3 ft s⁻¹), as measured by a vane-type anemometer in the areas in 7.1.12.1 and 7.1.12.2:

7.1.12.1 At the floor level where the burner is positioned during the test, and

7.1.12.2 At 1.50 m ± 0.05 m (4.9 ft ± 2 in.) above the enclosure floor, where the cable tray is positioned during the test.

7.2 Exhaust Collection System:

7.2.1 Construct the exhaust collection system containing, as a minimum: a blower, a steel hood, a duct, a bidirectional probe, thermocouple(s), an oxygen measurement system, and a smoke obscuration measurement system (white light photocell lamp/detector or laser). Optional components of the exhaust

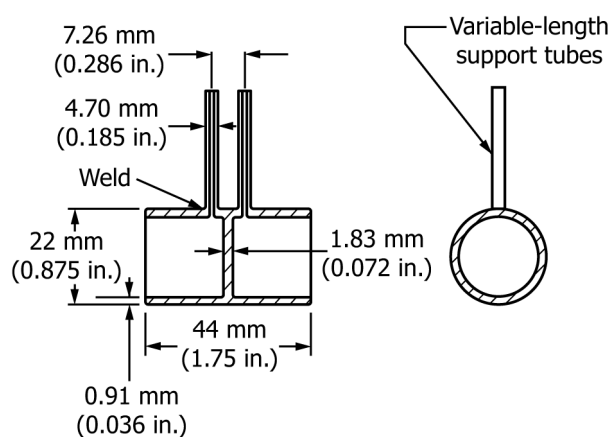


FIG. 2 Bidirectional Probe

collection system include a system for combustion gas sampling and analysis. Construct the exhaust collection system as explained in Annex A2 and Annex A3.

7.2.2 Ensure that the system for collecting the smoke (which includes gaseous combustion products) has sufficient exhaust capacity and is designed in such a way that all of the combustion products leaving the burning specimen are collected. Design the capacity of the evacuation system such that it will exhaust minimally all combustion gases leaving the cable specimen (see also Annex A2). Make the exhaust system capacity at least 2.7 m³ s⁻¹ (340 000 ft³ h⁻¹) at normal pressure and at a temperature of 25 °C ± 2 °C (77 °F ± 4 °F).

7.2.3 Place probes for sampling of combustion gas and for measurement of flow rate in accordance with 7.3.

7.2.4 Make all measurements of gas concentrations or flow rates at a position in the exhaust duct where the exhaust is uniformly mixed so that there is a nearly uniform velocity across the duct section (turbulent flow). Make the minimum straight section before the measuring system at least 8 times the inside diameter of the duct, to ensure the exhaust is uniformly mixed.

7.3 Instrumentation in Exhaust Duct:

7.3.1 The following specifications are minimum requirements for exhaust duct instrumentation. Additional information is found in Annex A1 through Annex A4.

7.3.2 Flow Rate:

7.3.2.1 Measure the volumetric flow rate in the exhaust duct by means of a bidirectional probe, or an equivalent measuring system, with an accuracy of at least ±6% (see Annex A1 – Annex A4). The response time to a stepwise change of the duct flow rate shall not exceed 5 s, to reach 90% of the final value.

7.3.2.2 Use a bidirectional probe or an equivalent measuring system to measure pressure in the duct. Locate the probe shown in Fig. 2 in the exhaust duct, at least 4.6 m (15 ft) but no more than 13.7 m (45 ft) from the centerline of the collection box.

7.3.2.3 Build a stainless steel bidirectional probe consisting of a cylinder 44 mm (1.75 in.) long and 22 mm (0.875 in.) in inside diameter with a solid diaphragm in the center. The pressure taps on either side of the diaphragm also provide support for mounting the probe. Position the long axis of the probe along the centerline of the duct. Connect the taps to a

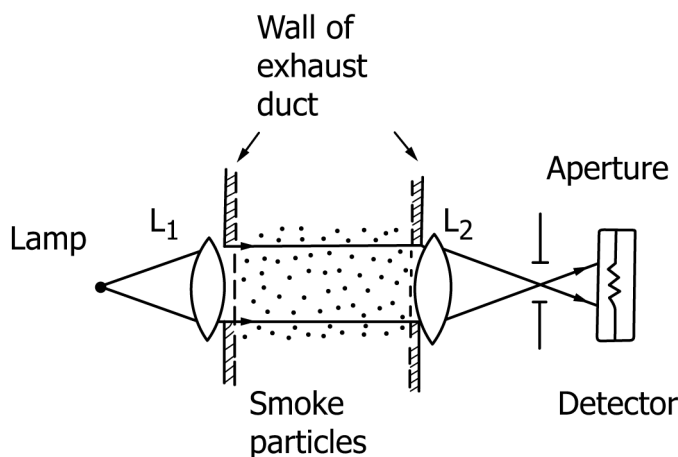


FIG. 3 Optical System

pressure transducer which can detect pressure differences as small as 0.25 Pa (0.001 in. of water).

7.3.2.4 Measure the mass flow rate as indicated in Annex A4.

7.3.2.5 Measure gas temperatures in the vicinity of the probe with Inconel sheathed Chromel-Alumel thermocouples. Ensure that the thermocouple does not disturb the flow pattern around the bidirectional probe. Further details are discussed in A1.3.

7.4 Smoke Obscuration Measurements:

7.4.1 Install an optical system for measurement of light obscuration across the centerline of the exhaust duct. Determine the optical density of the smoke by measuring the light transmitted with a photometer system consisting of a white light source and a photocell/detector or a laser system for measurement of light obscuration across the centerline of the exhaust duct. Locate the system so that it is preceded by at least eight diameters of duct without bends, to ensure a nearly uniform velocity across the duct section. If the system is positioned at a different location, demonstrate the achievement of equivalent results.

7.4.2 One photometer system found suitable consists of a lamp, lenses, an aperture and a photocell (see Fig. 3 and Annex A3). Construct the system so that soot deposits on the optics during a test do not reduce the light transmission by more than 5 %.

7.4.2.1 Alternatively, instrumentation constructed using a 0.5 mW to 2.0 mW helium-neon laser, instead of a white light system is also acceptable. See Fig. 4 and Annex A3 for further details. White light and laser systems give similar results (1-5)⁸.

7.5 Combustion Gas Analysis:

7.5.1 Sampling Line:

7.5.1.1 Construct the sampling line tubes using a material which is not affected by the combustion gas species, thereby influencing the concentration of the combustion gas species to be analyzed. The recommended sequence of the gas train is:

sampling probe, soot filter, cold trap, gas path pump, vent valve, plastic drying column and carbon dioxide removal columns (if used), flow controller and oxygen analyzer. Each analyzer in the gas train shall also include appropriate spanning and zeroing facilities.

7.5.1.2 Locate the sampling probe in a position where the exhaust duct flow is well mixed. Use a probe with a cylindrical cross section to minimize disturbance of the air flow in the duct. Collect the gas samples along the whole diameter of the exhaust duct.

7.5.1.3 Manufacture the sampling line, see Fig. 5, from corrosion resistant material, for example polytetrafluoroethylene. Remove the particulates contained in the combustion gases with inert filters to the degree required by the gas analysis equipment. Preferably filter the gases in more than one step. Cool the gas mixture to a maximum of 10 °C and dry the gas samples completely before the smoke reaches each analyzer.

7.5.1.4 Use a pump for the combustion gases which does not allow the gases to contact oil, grease or similar products, all of which can contaminate the gas mixture. A membrane pump is suitable.

7.5.1.5 A suitable sampling probe is shown in Fig. 6. This sampling probe is of the bar type. Ring type sampling probes are also acceptable, although they do not collect gas samples across the full diameter of the duct. The sampling line is shown in Fig. 5. A suitable pump has a capacity of 10 L min⁻¹ to 50 L min⁻¹ at 10 kPa (minimum), as each gas analysis instrument consumes about 1 L min⁻¹. A pressure differential of at least 10 kPa, as generated by the pump, reduces the risk of smoke clogging of the filters. Turn the intake of the sampling probe downstream to avoid soot clogging the probe.

7.5.1.6 Install a soot filter, capable of removing all particles >25 µm in size.

7.5.1.7 A refrigerated column is the most successful approach to cool and dry the gases. Provide a drain plug to remove the collected water from time to time. Alternative devices are also acceptable.

7.5.1.8 If carbon dioxide is to be removed, it is important to use carbon dioxide removal media, as indicated in Fig. 5.

7.5.2 Oxygen Measurement:

7.5.2.1 Measure the oxygen concentration with an accuracy of at least ± 0.04 % of full scale in the output range of 0 to 21 vol % oxygen, or ± 0.01 vol % oxygen, in order to have adequate measurements of rate of heat release. Take the combustion gas sample from the end of the sampling line. Calculate the time delay, including the time constant of the instrument, from the test room; it is a function of the exhaust duct flow rate. This time delay shall not exceed 60 s.

7.5.2.2 Use an oxygen analyzer, meeting the specifications of 7.5.2.1, preferably of the paramagnetic type.

7.6 Cable Tray:

7.6.1 Use a steel ladder cable tray, 300 mm ± 25 mm (12 in. ± 1 in.) wide, 75 mm ± 6 mm (3 in. ± 0.25 in.) deep, and 2440 mm ± 25 mm (8 ft ± 1 in.) long. Arrange the tray so that the burner flame will impinge on the cables midway between rungs.

⁸ The boldface numbers in parentheses refer to the list of references at the end of this test method.

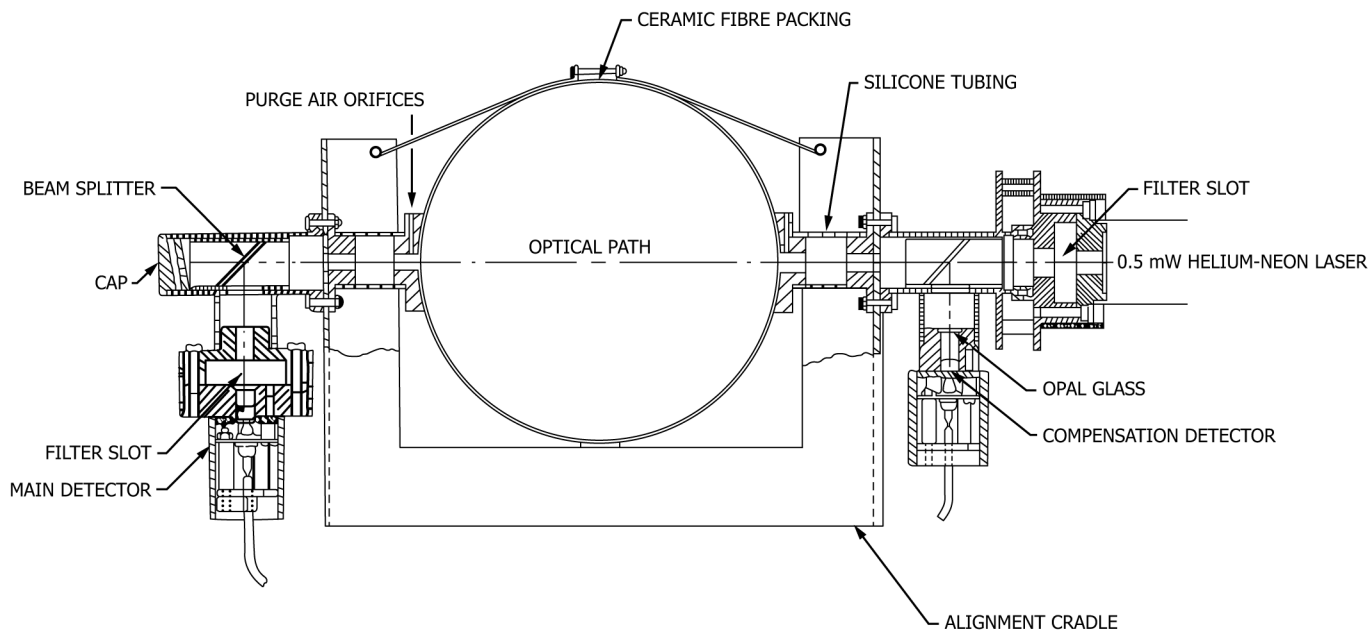


FIG. 4 Laser Extinction Beam

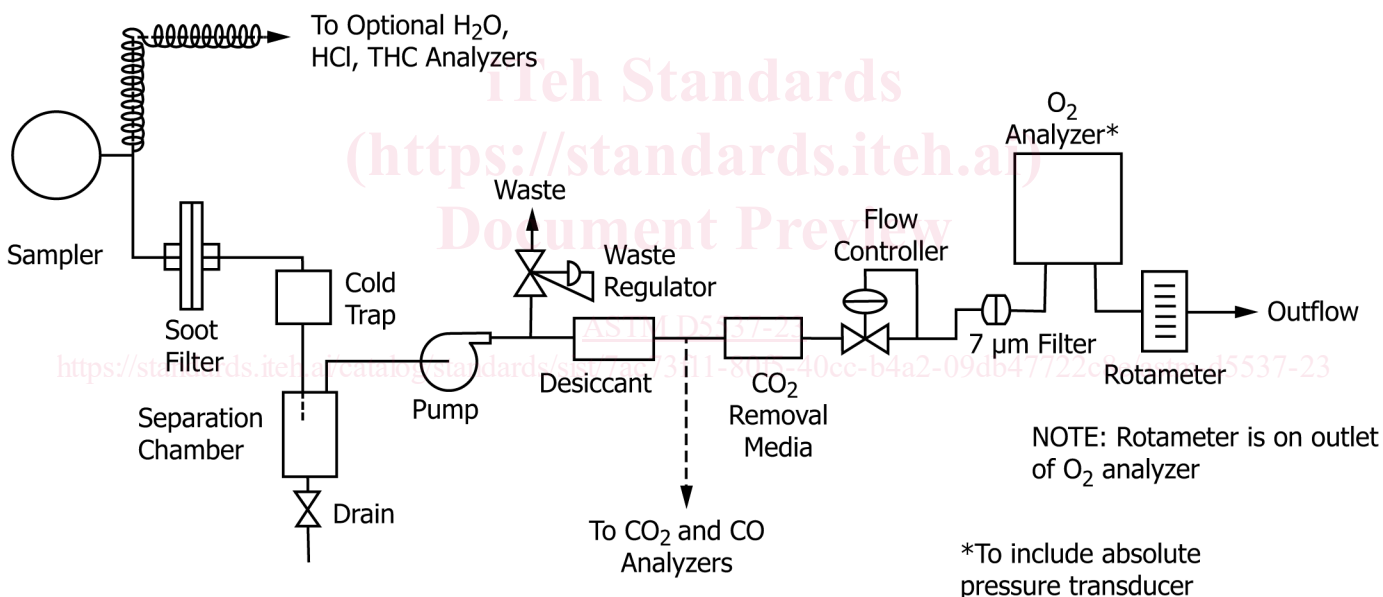


FIG. 5 Schematic Diagram of Gas Analysis System

7.6.1.1 Each rung in the tray is to measure $25 \text{ mm} \pm 6 \text{ mm}$ (1 in. \pm 0.25 in.) in the direction parallel to the length of the tray and $13 \text{ mm} \pm 3 \text{ mm}$ (0.5 in. \pm 0.125 in.) in the direction parallel to the depth of the tray.

7.6.1.2 Space the rungs $230 \text{ mm} \pm 13 \text{ mm}$ (9 in. \pm 0.5 in.) apart (measured center to center).

7.6.1.3 Attach the rungs to the side rails.

7.6.1.4 Mount the cable tray vertically in the center of the enclosure. Position the tray on a tray base (stand) which is to be no higher than $150 \text{ mm} \pm 25 \text{ mm}$ (6 in. \pm 1 in.).

7.7 Burner:

7.7.1 Use a 254 mm (10-in.) strip or ribbon type propane gas burner with an air/gas Venturi mixer.

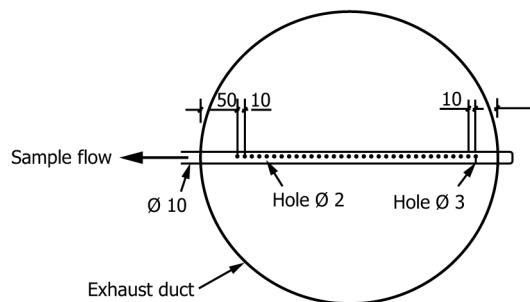


FIG. 6 Sampling Probe

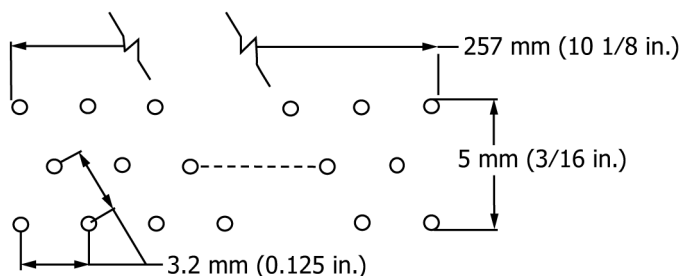


FIG. 7 Burner Holes

7.7.2 The flame producing surface of the burner consists essentially of a flat metal plate that is 341 mm (13⁷/₁₆ in.) long and 30 mm (1¹/₃₂ in.) wide. The plate has an array of 242 holes drilled in it. The holes are 1.35 mm (metric drill size: 1.35 mm) or 0.052 in. (No. 55 drill) in diameter, on 3.2 mm (0.125-in.) centers in three staggered rows of 81, 80, and 81 holes each, to form an array measuring 257 mm (10¹/₈ in.) by 5 mm (³/₁₆ in.). Center the array of holes on the plate (see Fig. 7).

7.7.3 Protocol A:

7.7.3.1 Position the burner behind the cable tray containing the specimen, with the flame-producing surface (face) of the burner vertical and its long dimension horizontal and with the 257 mm (10¹/₈-in.) dimension of the array of holes spaced 76 mm ± 5 mm (3.0 in. ± 0.2 in.) from the specimens in the tray and centered midway between the side rails of the tray. Position the centerpoint of the array of holes at 460 mm (18 in.) above the bottom end of the tray and specimen and midway between two rungs. Support the burner in a manner that allows it quick removal and precise repositioning of the burner to the position described. The tray faces the door.

7.7.4 Protocol B:

7.7.4.1 Mount the burner on a stand and place it 20° ± 2° from the horizontal with the burner ports up, in front of the cable tray. Locate the major axis of the burner ports 305 mm ± 25 mm (12 in. ± 1 in.) above the base of the cable tray and parallel to the cable tray rungs during the fire test (Fig. 8). The tray faces away from the door.

7.7.4.2 Attach a guide to the burner or stand such that the leading edge of the burner face is located quickly and accurately 75 mm ± 5 mm (3 in. ± 0.2 in.) horizontally away from the nearest surface of the cables during the burn period of the test.

7.7.5 Insert a flowmeter in both the propane and the air lines feeding the burner to measure the flow rates of these gases during the test.

7.7.6 Use a propane flowmeter capable of measuring at least 230 cm³ s⁻¹ (29 ft³ h⁻¹) and an air flowmeter of at least 1330 cm³ s⁻¹ (170 ft³ h⁻¹). Make flow rate measurements with an accuracy of ±3 %. Mass flow controllers with recordable outputs are permitted alternatives.

7.7.7 Supply compressed air to the burner, either bottled or from a compressed air system. Filter the air supply sufficiently so as to eliminate any contaminants that might affect the test results.

7.7.8 Use air with a dew point no greater than 0 °C (32 °F), as measured by a dew point measuring device.

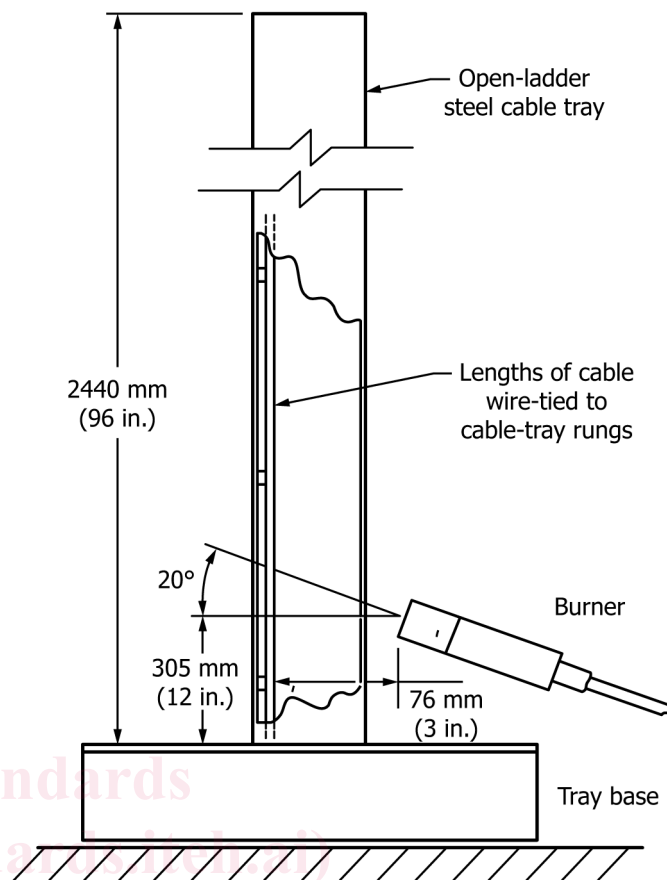


FIG. 8 Protocol B Cable Tray

7.7.9 Use CP grade propane (99 % pure), having a heat content of approximately 50.8 MJ kg⁻¹ (21.7 k Btu lb⁻¹) (93.0 MJ m⁻³ at 20 °C, 101 kPa), for the burner.

7.7.10 Use a propane flow rate of 220 cm³ s⁻¹ ± 8 cm³ s⁻¹ (28 ft³ h⁻¹ ± 1 ft³ h⁻¹) when corrected to standard temperature and pressure (20 °C, 101 kPa). This propane flow will provide a theoretical heat output of 20 kW (approximately 70 000 Btu h⁻¹). The actual heat output is less, due to incomplete combustion of the propane at the burner. Accurate flow rates of propane gas are calculated using the mass flow rate equations.

7.7.11 Use an air flow rate to the burner of 1280 cm³ s⁻¹ ± 80 cm³ s⁻¹ (163 ft³ h⁻¹ ± 10 ft³ h⁻¹) when corrected to standard temperature and pressure.

7.8 Mass Loss Measuring Device:

7.8.1 Use a mass measuring device, such as a load cell, to continuously measure the mass loss of the burning specimen.

7.8.2 The mass measuring device needs to measure the specimen mass with an accuracy of at least ±45 g (1.6 oz) up to at least 90 kg (198 lb) of specimen mass. Install it in such a way that the heat from the burning specimen and any eccentricity of the load does not affect the accuracy. Avoid range shifts during measurements. Protect all parts of the weight measuring device by a thermal barrier.

7.8.3 There are two alternative locations for the mass measuring device, as described in 7.8.4 – 7.8.6.

7.8.4 Alternative 1—Place the mass measuring device under a platform, with a thermal barrier of dimensions 0.3 m ±

0.05 m by 0.3 m ± 0.05 m (1 ft ± 2 in. by 1 ft ± 2 in.) and of a non-combustible material, for example calcium silicate boards. Provide the platform with sides of 0.1 m ± 10 mm (4 in. ± 0.4 in.) height in order to prevent melting or falling material from the tested specimens from falling off the thermal barrier.

7.8.5 Do not exceed 0.5 m (20 in.) from the upper surface of the thermal barrier to floor level. Shield the area between the thermal barrier and the floor level to avoid lifting forces due to fire induced air flow that could influence the measurement. Ensure that there are virtually no obstructions to the air supply for the test set-up.

7.8.6 *Alternative 2*—Place the mass measuring device in the hood and hang the cable tray from it. Thermal and combustion gas protection of the mass measuring equipment is still required.

7.8.7 Place a square galvanized steel platform under the cable tray. The platform shall be constructed of nominally 1.6 mm (1/16 in.) thick steel, and have dimensions of no less than 1.0 m by 1.0 m (approximately 39 in. by 39 in.), with a uniform raised lip, 100 mm (approximately 4 in.) high, on each side, to catch falling material. The platform shall be covered by a tight fitting sheet of standard gypsum board, of nominally 13 mm (0.5 in.) thickness. The platform shall protect the load cell, if it is placed underneath the cable tray. The gypsum board shall be clean before the start of a test. If the sheet used has been damaged it shall be replaced.

NOTE 2—A square galvanized steel platform of dimensions of up to 1.22 m by 1.22 m (approximately 4 ft by 4 ft) with a raised lip is also acceptable.

7.9 *Cable Mounting:*

7.9.1 *Protocol A*—Fasten 2440 mm ± 10 mm (96-in. ± 0.5-in.) specimen lengths of finished cable in a single layer in the tray by means of steel or copper wire, not larger than 2.1 mm² (14 AWG) in cross section, at their upper and lower ends and at two other equally spaced points along their lengths, with each cable vertical. Install as many specimens in the tray as will fit, spaced one half cable diameter apart, to fill the center 150 mm (6 in.) of the tray width.

7.9.1.1 Determine the number of specimen lengths for test using Eq 1:

$$N = [(4 \times 25.4)/D] + 0.33 \quad (1)$$

where:

- N = number of cables (rounded up to the nearest whole number), and
- D = diameter of the cable, mm.

7.9.2 *Protocol B*—Fasten 2440 mm ± 10 mm (96 in. ± 0.5 in.) specimen lengths of finished cable in the tray. Depending upon the outside diameter of the individual cables, the test specimen is to be either an individual length or a bundle of individual lengths. Center the specimens or specimen bundles in a single layer between the side rails of the cable tray. Ensure that the lower end of each specimen is no more than 100 mm (4 in.) above the bottom end of the cable tray. Attach each individual specimen or bundle of specimens separately to each rung of the cable tray using one wrap of a copper or steel wire tie not larger than 2.1 mm² (14 AWG) in diameter.

TABLE 1 Tray Loading for Circular Cables Smaller than 13 mm (0.5 in.) in Diameter

Cable Diameter, mm		Number of Cables in Each Bundle	Number of Bundles in Tray
From	But Less Than		
11	13	3	7
9	11	3	8
6	9	3	10
5	6	7	9
3	5	19	8
0	3	19	13

7.9.2.1 For cables smaller in diameter than 13 mm (0.5 in.), group the specimens into untwisted bundles (nominally circular) as shown in Table 1. Space the bundles one-half bundle diameter apart on the cable tray as measured at the point of attachment to the cable tray.

7.9.2.2 For cables 13 mm (0.5 in.) in diameter and larger, attach the individual specimens to the cable tray with spacings of 1/2 cable diameter, except do not exceed a spacing of 15 mm (0.6 in.). Table 2 shows the tray loading.

7.9.3 On flat cables, calculate the equivalent cable diameter using Eq 2

$$D = 1.128 \times \sqrt{(T \times W)} \quad (2)$$

where:

- D = calculated equivalent cable diameter,
- T = minor axis of the cable, and
- W = major axis of the cable.

8. Calibration

8.1 Calibrate all instruments carefully with standard sources after initial installation. Among the instruments to be calibrated are load cells or weighing platforms, smoke meters, flow or velocity transducers, and gas analyzers. Perform recalibration tests on the entire system, for example using standard output burners.

8.2 *Heat Release:*

8.2.1 Perform the calibration of the heat release instrumentation in the exhaust duct by burning propane gas and comparing the heat release rates calculated from the metered gas input, and those calculated from the measured oxygen consumption. The value of net heat of combustion for propane is 46.5 MJ/kg. Position the burner in the same location that the cable tray will occupy during the test. Measure the gas flow rate at a pressure of 101 kPa ± 5 kPa (standard atmospheric pressure, measured at the flow gage) and a temperature of 20 °C ± 5 °C. Use Eq A5.7 for calculation of heat release rate during calibration.

8.2.2 Obtain a minimum of two calibration points. Obtain a lower heat release rate value of 40 kW and then a higher heat release rate value of 160 kW. Approximate propane flow rates for any required heat release rate value are estimated using the following constant: 1.485 kW min/L, determined at a pressure of 101 kPa ± 5 kPa (standard atmospheric pressure; measured at the flow gage) and a temperature of 20 °C ± 5 °C.

8.2.3 Take measurements at least once every 6 s and start 1 min prior to ignition of the burner. Determine the average rate of heat release over a period of at least 1 min by (1) the oxygen consumption method, and (2) calculating the heat

TABLE 2 Tray Loading for Cables 13 mm (0.5 in.) in Diameter and Larger

Cable Diameter, mm		Number of Cables in Tray
From	But Less Than	
13	15	11
15	19	9
19	21	8
21	26	7
26	28	6
28	39	5
39	52	4
52	73	3
73	120	2

release rate from the gas mass flow rate and the net heat of combustion. The two values must agree within 5 %. Make this comparison only after steady state conditions are reached.

8.2.4 Perform a calibration test in accordance with 8.2.1 and 8.2.3 prior to each continuous test series. Perform a full basic calibration on a new system or when modifications are introduced.

8.2.5 When calibrating a new system, or when modifications are introduced, check the response time of the measuring system by the following test sequence:

Time	Burner Output
0 to 5 min	0 kW
5 to 10 min	40 kW
10 to 15 min	160 kW
15 to 20 min	0 kW

The response of the system to a stepwise change of the heat output from the burner shall be a maximum of 12 s to 90 % of final value.

8.2.6 Perform the calibration in 8.2.5 at a duct air flow rate comparable to that to be used in the test procedure.

8.2.7 Determine the time average value, over 1 min, of rate of heat release at each minute. The difference between these time averaged measured rate of heat release values and the actual heat output from the burner, shall not be more than 10 % of the actual value.

8.3 Mass Loss:

8.3.1 Perform calibration of the mass measuring device by loading the weighing platform with known masses corresponding to the measuring range of interest, to ensure that the requirements of accuracy in 7.8.2 are fulfilled. Carry out this calibration daily, prior to testing.

8.4 Smoke Release:

8.4.1 Prior to the start of each day of testing, verify the linearity of the photometer system by interrupting the light beam with multiple calibrated neutral density filters to cover the range of the recording instrument. Use at least two neutral density filters of significantly different values, and also one for 100 % transmission. Ensure that the transmittance values measured by the photometer, using neutral density filters, are within ± 3 % of the specified value for each filter.

9. Conditioning

9.1 Prior to testing, condition the cable specimen for at least 3 h in an atmosphere at a temperature of $23\text{ }^{\circ}\text{C} \pm 5\text{ }^{\circ}\text{C}$ ($73\text{ }^{\circ}\text{F} \pm 10\text{ }^{\circ}\text{F}$) with a relative humidity of less than 55 %. Test cables

within 10 min of removal from such conditions if test room conditions differ from the preceding conditions.

10. Procedure

10.1 Do not carry out the test if the temperature of the chamber wall is below $5\text{ }^{\circ}\text{C}$ ($41\text{ }^{\circ}\text{F}$) or above $30\text{ }^{\circ}\text{C}$ ($86\text{ }^{\circ}\text{F}$).

10.2 Establish an initial volumetric flow rate of $0.65\text{ m}^3\text{ s}^{-1} \pm 0.05\text{ m}^3\text{ s}^{-1}$ ($23\text{ ft}^3\text{ s}^{-1} \pm 2\text{ ft}^3\text{ s}^{-1}$) through the duct. See Annex A1 for the measuring techniques and for the equation to calculate volumetric flow rate of the gas in the duct (Eq A1.1). Record the volumetric flow rate as a function of time, starting 1 min prior to the test. Do not change the flow rate once the initial flow rate is established.

10.3 Position the prepared cable tray vertically inside the enclosure with the open front of the cable tray facing the front of the enclosure. Fix the cable tray firmly in position.

10.4 Start all recording and measuring devices before starting the ignition burner, to ensure they are stabilized.

10.5 Ignite the gas mixture in the burner and adjust the gas flows to the values specified in 7.7.10 and 7.7.11. Position the burner as indicated in 7.7.3 (Protocol A) or 7.7.4 (Protocol B). See Fig. 8 for the relative positions of the cable tray and burner in the enclosure.

10.6 Allow the burner flame to impinge on the cable specimen for a continuous period of 20 min.

10.7 At 20 min, extinguish the burner flame, but allow the cable fire (if any) to burn out.

10.8 Optionally, photograph or video record before and during the test. Include a clock, giving time to the nearest 1 s, in all photographic records.

10.9 During the test, record the following events and the time interval when they occur (beginning and end).

- 10.9.1 Ignition of the specimen,
- 10.9.2 Position of flame front,
- 10.9.3 Melting and dripping,
- 10.9.4 Occurrence of pool fire under the specimen,
- 10.9.5 General description of the burning behavior,
- 10.9.6 Time of afterburn, after extinguishing the propane, and
- 10.9.7 Any other event of special interest.

NOTE 3—It is possible for ignition of the cables to occur almost immediately after ignition of the burner. However, time to ignition of the cables is occasionally difficult to determine.

10.10 Conduct the procedure in duplicate. Conduct each procedure (burn) on untested cable specimens.

10.11 Evaluation of Damage:

10.11.1 After burning has ceased, let the cables and tray cool to room temperature, then wipe the cables clean with a cloth and determine cable damage.

10.11.1.1 Protocol A—Determine the maximum height of cable damage by measuring the blistering, char, and other damage upward from the bottom of the vertical tray.

10.11.1.2 Protocol B—Determine the maximum height of cable damage by measuring the blistering, char, and other damage from the lower edge of the burner face.

10.11.2 Determine the limit of charring by pressing against the cable surface with a sharp object. Where the surface of the cable (outer jacket, if any) changes from a resilient surface to a brittle (crumbling) surface determines the limit of charring. Include distortion of the outer surface of the cable, such as blistering or melting, immediately above the char, in the damage measurement.

10.11.3 Record the cable damage (char) to the nearest 25 mm (1 in.). On cable constructions that do not have charring, define the limit for the affected portion as the point where the overall diameter is visibly reduced or increased.

10.11.4 For engineering information, record damage such as blistering, or softening/melting of combustible material above the char.

10.12 *Heat Release Measurements:*

10.12.1 Make continuous measurements of heat release by measuring oxygen concentration and mass flow rate in the exhaust duct.

10.12.2 From these measurements and the equations in **Annex A5** determine the rates and amounts of heat release. These values together with the visual recordings constitute the results from the test.

11. Calculation

11.1 Considerations for heat release measurements are presented in **Appendix X2**. The corresponding equations for heat release calculations are presented in **Annex A5**. The testing laboratory shall choose which of the equations in **Annex A5** it wishes to use for the heat release calculations. Equations for smoke release calculations are presented in **Annex A6**.

12. Report

12.1 Report the following information:

12.1.1 *Descriptive Information:*

- 12.1.1.1 Name and address of the testing laboratory,
- 12.1.1.2 Inside dimensions of enclosure,
- 12.1.1.3 Date and identification number of the report,
- 12.1.1.4 Methods of sampling for selecting the test specimens,

12.1.1.5 Name of product manufacturer or supplier, if known,

12.1.1.6 Name or other identification marks and description of the product,

12.1.1.7 Density, or weight per unit surface, and total mass, thickness of the main components in the product (including jacket and insulation), and mass of combustible portion of product, if known,

12.1.1.8 Description of the samples,

12.1.1.9 Conditioning of the specimens,

12.1.1.10 Date of test, and

12.1.1.11 Test number, Protocol (A or B) and any special remarks.

12.1.2 *Test Results:*

12.1.3 *Table of Mandatory Numerical Results Containing:*

- 12.1.3.1 Maximum char damage, m,
 - 12.1.3.2 Peak rate of heat release, kW, and the appropriate time at which it occurred,
 - 12.1.3.3 Total heat released, MJ,
 - 12.1.3.4 Time of afterburn, s,
 - 12.1.3.5 Peak rate of smoke release, $m^2 s^{-1}$, and the appropriate time at which it occurred,
 - 12.1.3.6 Total smoke released, m^2 ,
 - 12.1.3.7 Total mass loss, g,
 - 12.1.3.8 Percentage of mass loss, %,
 - 12.1.3.9 Peak flame height, m, and the appropriate time at which it occurs,
 - 12.1.3.10 Peak mass loss rate, $g s^{-1}$,
 - 12.1.3.11 Average mass loss rate, over the entire burn, $g s^{-1}$, and
 - 12.1.3.12 Equation used to calculate rate of heat release.
- 12.1.4 *Additional Table of Mandatory Numerical Results Containing:*

- 12.1.4.1 Total heat release data after every minute,
 - 12.1.4.2 Rate of heat release data after every minute,
 - 12.1.4.3 Total smoke release data after every minute,
 - 12.1.4.4 Rate of smoke release data after every minute,
 - 12.1.4.5 Mass loss rate data after every minute, and
 - 12.1.4.6 Volumetric flow rate after every minute.
- 12.1.5 *Mandatory Graphical Results:*
- 12.1.5.1 Plot of rate of heat release versus time,
 - 12.1.5.2 Plot of total heat released versus time,
 - 12.1.5.3 Plot of rate of smoke release versus time,
 - 12.1.5.4 Plot of total smoke released versus time, and
 - 12.1.5.5 Plot of mass loss rate versus time.

12.1.6 *Descriptive Results:*

- 12.1.6.1 Photographs or videotape, if available, of the fire development, and
- 12.1.6.2 All available information listed in **10.9**.

13. Precision and Bias

13.1 *Precision*—The precision of this test method has not been determined. Results of a planned interlaboratory test series will be included when available.

13.2 *Bias*—The true value of fire performance of electrical or optical fiber cables can only be defined in terms of a test method. Within this limitation, this test method has no known bias and can be accepted as a reference method.

14. Keywords

14.1 cable; cable tray; calorimetry; carbon dioxide; carbon monoxide; char; electrical cable; electrical insulation; fire; fire-test response; flame; heat release; heat release rate; ignition; optical density; optical fiber cable; oxygen consumption calorimetry; smoke obscuration; smoke release; toxic gases

ANNEXES
(Mandatory Information)
A1. VOLUMETRIC FLOW RATE

A1.1 One technique for measuring the flow is a bidirectional probe located at the center line of the duct. The probe shown in Fig. 2 consists of a stainless steel cylinder, 44 mm (1.75 in.) long and with an inner diameter of 22 mm (0.875 in.). The cylinder has a solid diaphragm in the center, dividing it into two chambers. The pressure difference between the two chambers is measured by a differential pressure transducer.

A1.2 Use a differential pressure transducer with an accuracy of at least ± 0.25 Pa (0.001 in. of water) and of the capacitance type. A suitable range of measurement is 0 Pa to 150 Pa.

A1.3 Place one thermocouple 152 mm \pm 25 mm (6 in. \pm 1 in.) upstream from the bidirectional probe. Use an Inconel sheathed 24 AWG (0.51 mm (0.020 in.) in diameter)

thermocouple, type K Chromel-Alumel. Place the thermocouple wire, within 13 mm (0.5 in.) of the bead, along expected isotherms to minimize conduction errors. Use an insulation between the Chromel and Alumel wires that is stable to at least 1100 °C (2000 °F). Ensure that the thermocouple does not disturb the flow pattern around the bidirectional probe.

A1.4 The volumetric flow rate, in $\text{m}^3 \text{s}^{-1}$, in the duct under standard conditions is calculated in accordance with Eq A1.1 as follows (symbols in A5.3):

$$V_s = C_v k_c A \sqrt{\left[\frac{2\Delta_p}{\rho_o} \frac{T_o}{T} \right]} = 20.1 k_c A \sqrt{\left[\frac{\Delta p}{T} \right]} \quad (\text{A1.1})$$

A2. DESIGN OF EXHAUST SYSTEM
A2.1 Hood and Exhaust Duct, Recommended Design:

A2.1.1 Collect the combustion gases from the burning specimen by means of a hood. A system is described in A2.1.2 which was tested in practice and proven to fulfill the specifications given in this test method.

A2.1.2 The hood is located above the room. The bottom dimensions of the hood are 2.44 m by 2.44 m (96 in. by 96 in.) (see Fig. 1). The hood feeds into a cubical box/plenum having 0.910 mm \pm 0.025 mm (36 in. \pm 1 in.) as the dimension of each side. A maximum height of 1.80 m \pm 0.1 m (71 in. \pm 4 in.), to satisfy building constraints, is acceptable. Underneath the hood, locate a baffle plate approximately 0.6 m by 0.6 m (2 ft by 2 ft) (see Fig. 1), to increase mixing of the combustion gases. Design and manufacture the hood and its attachment to the chamber so that no leakage exists.

A2.1.3 If a laser beam is used, a suitable way of mounting the beam together with the gas sampling probes is shown in Fig. A2.1.

A2.1.4 Connect an exhaust duct with the plenum chamber. The inner diameter of the exhaust duct is 410 mm \pm 25 mm (16 in. \pm 1 in.). To facilitate flow measurements, locate guide vanes, if needed, at both ends of the exhaust duct.

Alternatively, make the rectilinear part of the exhaust duct long enough that a fully-developed flow profile is established at the point of measurement. Connect the exhaust duct to an evacuation system.

A2.1.5 Design the capacity of the evacuation system so as to exhaust minimally all combustion gases leaving the specimen. This requires an exhaust capacity of at least 2.7 kg s^{-1} (about 8000 $\text{m}^3 \text{h}^{-1}$ at standard atmospheric conditions) corresponding to a driving under pressure of about 2 kPa at the end of the duct. Provide a means to control the exhaust flow from 0.5 kg s^{-1} up to maximum flow as stated previously during the test process. Ensure that the measurement system has sufficient sensitivity for measurement of low rates of heat release. Use mixing vanes in the duct if concentration gradients are found to exist. An alternative system for dealing with concentration gradients is acceptable if it is shown to produce equivalent results.

A2.1.6 An alternative exhaust system design is acceptable if it is shown to produce equivalent results. Equivalency is demonstrated by meeting the calibration requirements of Section 8. Exhaust system designs based on natural convection are unacceptable.