

# NFPA 287

## Standard

### Test Methods for

### Measurement of Flammability

### of Materials in Cleanrooms

### Using a Fire Propagation

### Apparatus (FPA)

## 2001 Edition



NFPA, 1 Batterymarch Park, PO Box 9101, Quincy, MA 02269-9101  
An International Codes and Standards Organization

NFPA License Agreement

This document is copyrighted by the National Fire Protection Association (NFPA), 1 Batterymarch Park, Quincy, MA 02269-9101 USA.  
All rights reserved.

NFPA grants you a license as follows: The right to download an electronic file of this NFPA document for temporary storage on one computer for purposes of viewing and/or printing one copy of the NFPA document for individual use. Neither the electronic file nor the hard copy print may be reproduced in any way. In addition, the electronic file may not be distributed elsewhere over computer networks or otherwise. The hard copy print may only be used personally or distributed to other employees for their internal use within your organization.

## IMPORTANT NOTICE ABOUT THIS DOCUMENT

NFPA codes, standards, recommended practices, and guides, of which the document contained herein is one, are developed through a consensus standards development process approved by the American National Standards Institute. This process brings together volunteers representing varied viewpoints and interests to achieve consensus on fire and other safety issues. While the NFPA administers the process and establishes rules to promote fairness in the development of consensus, it does not independently test, evaluate, or verify the accuracy of any information or the soundness of any judgments contained in its codes and standards.

The NFPA disclaims liability for any personal injury, property or other damages of any nature whatsoever, whether special, indirect, consequential or compensatory, directly or indirectly resulting from the publication, use of, or reliance on this document. The NFPA also makes no guaranty or warranty as to the accuracy or completeness of any information published herein.

In issuing and making this document available, the NFPA is not undertaking to render professional or other services for or on behalf of any person or entity. Nor is the NFPA undertaking to perform any duty owed by any person or entity to someone else. Anyone using this document should rely on his or her own independent judgment or, as appropriate, seek the advice of a competent professional in determining the exercise of reasonable care in any given circumstances.

The NFPA has no power, nor does it undertake, to police or enforce compliance with the contents of this document. Nor does the NFPA list, certify, test or inspect products, designs, or installations for compliance with this document. Any certification or other statement of compliance with the requirements of this document shall not be attributable to the NFPA and is solely the responsibility of the certifier or maker of the statement.

*See inside back cover for additional important notices and information.*

## NOTICES

All questions or other communications relating to this document and all requests for information on NFPA procedures governing its codes and standards development process, including information on the procedures for requesting Formal Interpretations, for proposing Tentative Interim Amendments, and for proposing revisions to NFPA documents during regular revision cycles, should be sent to NFPA headquarters, addressed to the attention of the Secretary, Standards Council, National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101.

Users of this document should be aware that this document may be amended from time to time through the issuance of Tentative Interim Amendments, and that an official NFPA document at any point in time consists of the current edition of the document together with any Tentative Interim Amendments then in effect. In order to determine whether this document is the current edition and whether it has been amended through the issuance of Tentative Interim Amendments, consult appropriate NFPA publications such as the *National Fire Codes*® Subscription Service, visit the NFPA website at [www.nfpa.org](http://www.nfpa.org), or contact the NFPA at the address listed above.

A statement, written or oral, that is not processed in accordance with Section 6 of the Regulations Governing Committee Projects shall not be considered the official position of NFPA or any of its Committees and shall not be considered to be, nor be relied upon as, a Formal Interpretation.

The NFPA does not take any position with respect to the validity of any patent rights asserted in connection with any items which are mentioned in or are the subject of this document, and the NFPA disclaims liability for the infringement of any patent resulting from the use of or reliance on this document. Users of this document are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, is entirely their own responsibility.

Users of this document should consult applicable federal, state, and local laws and regulations. NFPA does not, by the publication of this document, intend to urge action that is not in compliance with applicable laws, and this document may not be construed as doing so.

## **Licensing Policy**

This document is copyrighted by the National Fire Protection Association (NFPA). By making this document available for use and adoption by public authorities and others, the NFPA does not waive any rights in copyright to this document.

**1. Adoption by Reference**—Public authorities and others are urged to reference this document in laws, ordinances, regulations, administrative orders, or similar instruments. Any deletions, additions, and changes desired by the adopting authority must be noted separately. Those using this method are requested to notify the NFPA (Attention: Secretary, Standards Council) in writing of such use. The term "adoption by reference" means the citing of title and publishing information only.

**2. Adoption by Transcription**—**A.** Public authorities with lawmaking or rule-making powers only, upon written notice to the NFPA (Attention: Secretary, Standards Council), will be granted a royalty-free license to print and republish this document in whole or in part, with changes and additions, if any, noted separately, in laws, ordinances, regulations, administrative orders, or similar instruments having the force of law, provided that: (1) due notice of NFPA's copyright is contained in each law and in each copy thereof; and (2) that such printing and republication is limited to numbers sufficient to satisfy the jurisdiction's lawmaking or rule-making process. **B.** Once this NFPA Code or Standard has been adopted into law, all printings of this document by public authorities with lawmaking or rule-making powers or any other persons desiring to reproduce this document or its contents as adopted by the jurisdiction in whole or in part, in any form, upon written request to NFPA (Attention: Secretary, Standards Council), will be granted a nonexclusive license to print, republish, and vend this document in whole or in part, with changes and additions, if any, noted separately, provided that due notice of NFPA's copyright is contained in each copy. Such license shall be granted only upon agreement to pay NFPA a royalty. This royalty is required to provide funds for the research and development necessary to continue the work of NFPA and its volunteers in continually updating and revising NFPA standards. Under certain circumstances, public authorities with lawmaking or rule-making powers may apply for and may receive a special royalty where the public interest will be served thereby.

**3. Scope of License Grant**—The terms and conditions set forth above do not extend to the index of this document.

(For further explanation, see the Policy Concerning the Adoption, Printing, and Publication of NFPA Documents, which is available upon request from the NFPA.)

Copyright © 2001 NFPA, All Rights Reserved

## **NFPA 287**

### **Standard Test Methods for**

# **Measurement of Flammability of Materials in Cleanrooms Using a Fire Propagation Apparatus (FPA)**

## **2001 Edition**

This edition of NFPA 287, *Standard Test Methods for Measurement of Flammability of Materials in Cleanrooms Using a Fire Propagation Apparatus (FPA)*, was prepared by the Technical Committee on Fire Tests and acted on by the National Fire Protection Association, Inc., at its November Meeting held November 12–15, 2000, in Orlando, FL. It was issued by the Standards Council on January 13, 2001, with an effective date of February 9, 2001.

This edition of NFPA 287 was approved as an American National Standard on February 9, 2001.

### **Origin and Development of NFPA 287**

This standard is based on an apparatus developed by Factory Mutual Research Corporation (FMRC) in the mid-1970s and since then has been constructed from the original FMRC design by several organizations. It is currently in active use at Underwriters Laboratories in the United States; Gilbert International Ltd, Manchester, UK; INERIS, Verneuil en Halatte, France; and Rhone-Poulenc Research Center, Decines, France. The apparatus associated test methods are distinct from other fire standards because of the focus on characterizing hazards associated with large-scale, self-sustained, upward, or flow-aided fire propagation on materials and products, not just the response of materials to an imposed, external heat flux.

This standard was developed to address those concerns of the Technical Committee for Cleanrooms through NFPA 318, *Standard for the Protection of Cleanrooms*.

## Technical Committee on Fire Tests

**Jesse J. Beitel**, *Chair*  
Hughes Assoc., Inc., MD [SE]

**Patty K. Adair**, American Textile Mfrs. Inst., DC [M]  
**April L. Berkol**, Starwood Hotels and Resorts, Inc., NY [U]  
Rep. American Hotel & Motel Assn.  
**John A. Blair**, The DuPont Co., DE [M]  
Rep. Society of the Plastics Industry Inc.  
**William E. Fitch**, Omega Point Laboratories Inc., TX [RT]  
**Thomas W. Fritz**, Armstrong World Industries Inc., PA [M]  
**James R. Griffith**, Southwest Research Institute, TX [RT]  
**Gordon E. Hartzel**, Hartzell Consulting, Inc., TX [SE]  
**Marcelo M. Hirschler**, GBH Int'l, CA [SE]  
**Alfred J. Hogan**, Reedy Creek Improvement District, FL [E]  
Rep. Int'l Fire Marshals Assn.  
**William E. Koffel, Jr.**, Koffel Assoc., Inc., MD [SE]  
**James R. Lawson**, U.S. Nat'l Inst. of Standards and Technology, MD [RT]  
**Gerald E. Lingenfelter**, American Ins Services Group Inc., NY [I]  
**Rodney A. McPhee**, Canadian Wood Council, Canada [M]

**William S. Metes**, Underwriters Laboratories Inc., IL [RT]  
**James A. Milke**, University of Maryland, MD [SE]  
**John Roberts**, Underwriters' Laboratories of Canada, Canada [RT]  
**Nigel R. Stamp**, Intertek Testing Services NA Inc., WI [RT]  
**Phil M. Stricklen**, Amoco Fabrics and Fibers, GA [M]  
**Kuma Sumathipala**, American Forest & Paper Assn., DC [M]  
**T. Hugh Talley**, Hugh Talley Co., TN [M]  
Rep. Upholstered Furniture Action Council  
**David K. Tanaka**, FM Global, MA [I]  
**Richard P. Thornberry**, The Code Consortium, Inc., CA [SE]  
**William A. Webb**, Performance Technology Consulting, Ltd, IL [SE]  
**Robert A. Wessel**, Gypsum Assn., DC [M]  
**Robert J. Wills**, American Iron & Steel Inst., AL [M]  
**Peter J. Gore Willse**, HSB Industrial Risk Insurers, CT [I]

### Alternates

**Kenneth G. Adams**, The Society of the Plastics Industry, DC [M]  
(Alt. to J. A. Blair)  
**Robert G. Bill, Jr.**, FM Global, MA [I]  
(Alt. to D. K. Tanaka)  
**Delbert F. Boring, Jr.**, American Iron & Steel Inst., OH [M]  
(Alt. to R. J. Wills)  
**Tony Crimi**, Underwriters' Laboratories of Canada, Canada [RT]  
(Alt. to J. Roberts)  
**Philip J. DiNunno**, Hughes Assoc., Inc., MD [SE]  
(Alt. to J. J. Beitel)  
**Sam W. Francis**, American Forest & Paper Assn., PA [M]  
(Alt. to K. Sumathipala)

**Richard G. Gann**, U.S. Nat'l Inst. of Standards and Technology, MD [RT]  
(Alt. to J. R. Lawson)  
**Marc L. Janssens**, Southwest Research Institute, TX [RT]  
(Alt. to J. R. Griffith)  
**John W. Michener**, Milliken Research Corp., SC [M]  
(Alt. to P. K. Adair)  
**Frederick W. Mowrer**, University of Maryland, MD [SE]  
(Alt. to J. A. Milke)  
**William A. Thornberg**, HSB Industrial Risk Insurers, CT [I]  
(Alt. to P. J. G. Willse)  
**James J. Urban**, Underwriters Laboratories Inc., IL [RT]  
(Alt. to W. S. Metes)  
**Joe Ziolkowski**, American Furniture Mfrs. Assn., NC [M]  
(Alt. to T. H. Talley)

### Nonvoting

**Robert H. Barker**, American Fiber Mfrs. Assn., DC [M]  
(Alt. to T. L. Jilg)  
**Tod L. Jilg**, Hoechst Celanese Corp., NC [M]  
**Rohit Khanna**, U.S. Consumer Product Safety Commission, MD [C]

**James C. Norris**, Couance Laboratories Ltd, England [SE]  
**Herman H. Spaeth**, Novato, CA  
(Member Emeritus)

**Walter P. Sterling**, NFPA Staff Liaison

*This list represents the membership at the time the Committee was balloted on the final text of this edition. Since that time, changes in the membership may have occurred. A key to classifications is found at the back of the document.*

NOTE: Membership on a committee shall not in and of itself constitute an endorsement of the Association or any document developed by the committee on which the member serves.

**Committee Scope:** This Committee shall have primary responsibility for documents on fire testing procedures, for reviewing existing fire test standards and recommending appropriate action to NFPA, for recommending the application of and advising on the interpretation of acceptable test standards for fire problems of concern to NFPA technical committees and members, and for acting in a liaison capacity between NFPA and the committees of other organizations writing fire test standards. This Committee does not cover fire tests that are used to evaluate extinguishing agents, devices, or systems.

## Contents

<b>Chapter 1 General</b> .....	287- 4	4.3 Specimen Size and Preparation.....	287-17
1.1 Scope.....	287- 4	4.4 Mounting Methods.....	287-17
1.2 Purpose.....	287- 4		
1.3 Definitions.....	287- 4	<b>Chapter 5 Test Procedure</b> .....	287-19
1.4 Symbols.....	287- 5	5.1 Procedure 1: Ignition Test.....	287-19
1.5 Units.....	287- 5	5.2 Procedure 2: Combustion Test.....	287-20
		5.3 Procedure 3: Fire Propagation Test.....	287-20
<b>Chapter 2 Test Apparatus</b> .....	287- 5	5.4 Safety Precautions.....	287-21
2.1 General.....	287- 5		
2.2 Infrared Heating System.....	287- 5	<b>Chapter 6 Calculations</b> .....	287-21
2.3 Load Cell System.....	287- 7	6.1 Critical Heat Flux (CHF).....	287-21
2.4 Ignition Pilot Flame.....	287- 7	6.2 Thermal Response Parameter (TRP).....	287-21
2.5 Ignition Timer.....	287- 7	6.3 Fire Propagation Index (FPI).....	287-21
2.6 Gas Analysis System.....	287- 8	6.4 Effective Heat of Combustion (EHC).....	287-21
2.7 Combustion Air Distribution System.....	287- 9	6.5 Smoke Yield ( $y_s$ ).....	287-22
2.8 Water-Cooled Shield.....	287-12	6.6 Convective Heat Release Rate.....	287-22
2.9 Exhaust System.....	287-12		
2.10 Test Section Instruments.....	287-14	<b>Chapter 7 Report</b> .....	287-22
2.11 Heat Flux Gauge.....	287-14	7.1 General Test Description and	
2.12 Digital Data Collection.....	287-14	Ignition Test.....	287-22
		7.2 Combustion Test.....	287-22
<b>Chapter 3 Calibration of Equipment</b> .....	287-16	7.3 Fire Propagation Test.....	287-22
3.1 Radiant Flux Heater.....	287-16		
3.2 Gas Analysis Equipment.....	287-16	<b>Chapter 8 Referenced Publications</b> .....	287-22
3.3 Load Cell.....	287-16		
3.4 Heat Release Calibration.....	287-16	<b>Appendix A Explanatory Material</b> .....	287-22
<b>Chapter 4 Test Specimens</b> .....	287-16	<b>Appendix B Background Material</b> .....	287-23
4.1 Specimen Holders.....	287-16		
4.2 Conditioning.....	287-17	<b>Appendix C Referenced Publications</b> .....	287-26
		<b>Index</b> .....	287-27

## NFPA 287

## Standard Test Methods for

Measurement of Flammability of Materials  
in Cleanrooms Using  
a Fire Propagation Apparatus (FPA)

## 2001 Edition

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

Information on referenced publications can be found in Chapter 8 and Appendix C.

## Chapter 1 General

## 1.1 Scope.

**1.1.1** This standard shall determine and quantify the flammability characteristics of materials containing polymers that are used in cleanroom applications. The propensity of these materials to support fire propagation, as well as other flammability characteristics, are quantified by means of a fire propagation apparatus. Measurements obtained include time to ignition ( $t_{ign}$ ), chemical ( $\dot{Q}_{chem}$ ), and convective ( $\dot{Q}_c$ ) heat release rates, mass loss rates ( $\dot{m}$ ), and smoke extinction coefficient ( $D$ ).

**1.1.2** This standard includes the following separate test methods:

- (1) The ignition test, which shall be used for the determination of  $t_{ign}$
- (2) The combustion test, which shall be used for the determination of  $\dot{Q}_{chem}$ ,  $\dot{Q}_c$ ,  $\dot{m}$ , and  $D$
- (3) The fire propagation test, which shall be used for the determination of  $\dot{Q}_{chem}$  from burning of a vertical specimen

## 1.2 Purpose.

**1.2.1\*** The test methods described herein evaluate the suitability of materials and products containing polymers for use in cleanrooms. These test methods also provide the transient response of such materials and products to prescribed heat fluxes in specified inert or oxidizing environments, for use in mathematical modeling. The fire propagation apparatus is also designed to obtain laboratory measurements of generation rates of fire products ( $\text{CO}_2$ ,  $\text{CO}$ , and, if desired, gaseous hydrocarbons).

**1.2.2** Distinguishing features of the fire propagation apparatus include the following:

- (1) Tungsten-quartz external (isolated) heaters to provide a radiant flux of up to  $65 \text{ kW/m}^2$  to the test specimen, this flux remaining constant whether the surface regresses or expands
- (2) Provision for combustion or upward fire propagation in prescribed flows of normal or either oxygen-enriched or oxygen-vitiated air
- (3) The capability of measuring heat release rates and exhaust product flows generated during self-sustained, upward fire propagation on a vertical test specimen  $0.305 \text{ m}$  high

- (4) The capability for characterization of the smoke yield from a specimen

**1.2.3\*** The test methods are part of a quantitative methodology for assessing the propensity of materials and products used in cleanrooms to support upward fire propagation and to generate effluent, such as smoke. This methodology consists of the correlation of flammability indices resulting from the test methods with corresponding characteristics measured during real-scale fire propagation experiments. Indices resulting from the test methods include critical heat flux (CHF), thermal response parameter (TRP), fire propagation index (FPI), effective heat of combustion (EHC), and smoke yield ( $y_s$ ). The TRP and CHF indices are obtained from the ignition test, the EHC and  $y_s$  indices are obtained from the combustion test, and the FPI is derived from a fire propagation test in air containing 40 percent oxygen.

**1.2.4 Summary of Test Methods.** This standard is composed of three separate test methods that shall be used in conjunction with a fire propagation apparatus. The ignition and combustion test methods shall involve the use of horizontal specimens, in normal air, subjected to a controlled external radiant heat flux that shall be set from 0 up to  $65 \text{ kW/m}^2$ . The ignition test method shall be conducted under ambient conditions, whereas the combustion and fire propagation test methods shall be conducted with a prescribed airflow within a quartz pipe. The fire propagation test method shall involve the use of vertical specimens, in air having a 40 percent (by volume) oxygen concentration, subjected to ignition near the base of the specimen from an external radiant heat flux of  $50 \text{ kW/m}^2$  and a pilot flame.

**1.2.4.1\*** The ignition test method shall be used to determine the TRP and CHF of horizontal specimens. The TRP shall be determined from changes in the time required for sustained ignition by a pilot flame as a function of the magnitude of a constant, externally applied radiant heat flux. The CHF shall be determined from the magnitude of externally applied radiant heat flux below which there is no sustained ignition. Measurements also shall be made of the time to initial fuel vaporization. The surface of the specimens shall be coated with a thin layer of black paint.

**1.2.4.2** The combustion test method shall be used to determine the EHC and  $y_s$ , as well as the chemical and convective heat release rates when the horizontal test specimen is exposed to an external radiant heat flux of  $50 \text{ kW/m}^2$  in the apparatus.

**1.2.4.3\*** The fire propagation test method shall be used to determine the FPI of vertical specimens. A 40 percent oxygen concentration in the inflow shall be used to simulate the radiant heat flux from real-scale flames.

**1.2.5** The fire propagation test of vertical specimens shall not be used for materials that melt and form a liquid pool while burning.

**1.2.6** This standard does not purport to address all safety problems associated with its use. It shall be the responsibility of the user of this standard to establish appropriate safety and health practices.

## 1.3 Definitions.

**1.3.1 Cleanroom (as defined in NFPA 318, *Standard for the Protection of Cleanrooms*).** A room in which the concentration of airborne particles is controlled to specified limits. Clean-

rooms include areas below the raised floor and above the ceiling grid if these areas are part of the air path and within the rated construction.

**1.3.2 Critical Heat Flux (CHF).** The minimum heat flux at or below which there is no ignition.

**1.3.3 Effective Heat of Combustion (EHC).** The energy generated by chemical reactions per unit mass of fuel vaporized.

**1.3.4 Fire Propagation Index (FPI).** The propensity of a material to support fire propagation beyond the ignition zone in terms of the chemical heat release rate during upward fire propagation and TRP.

**1.3.5 Smoke Yield ( $y_s$ ).** The mass of smoke particulates generated per unit mass of fuel vaporized.

**1.3.6 Thermal Response Parameter (TRP).** A material characteristic that gives resistance to ignition upon exposure to a prescribed heat flux.

**1.4 Symbols.** The following symbols are used in this document.

$A_d$  = cross-sectional area of test section duct ( $m^2$ )

CHF = critical heat flux ( $kW/m^2$ )

$c_p$  = specific heat of air at constant pressure ( $kJ/kg\ K$ )

$D$  = extinction coefficient obtained from test section duct turbidimeter ( $m^{-1}$ )

EHC = effective heat of combustion ( $kJ/kg$ )

FPI = fire propagation index ( $m^{5/3}/kW^{2/3}\ sec^{1/2}$ )

$\dot{G}_{CO}$  = mass flow rate of CO in test section duct ( $kg/sec$ )

$\dot{G}_{CO_2}$  = mass flow rate of  $CO_2$  in test section duct ( $kg/sec$ )

$I/I_a$  = ratio of light intensity measured by turbidimeter to the average value before ignition (—)

$K$  = flow coefficient of averaging Pitot tube [duct gas velocity/ $(2\Delta p_m/\rho)^{1/2}$ ] (—)

$L$  = light beam path length for turbidimeter in test section duct (m)

$M_{loss}$  = ultimate change in specimen mass resulting from a combustion test (kg)

$\dot{m}$  = mass loss rate of specimen resulting from combustion ( $kg/sec$ )

$\dot{m}_d$  = mass flow rate of gases in the test section duct ( $kg/sec$ )

$P_{atm}$  = atmospheric pressure (Pa)

$p_m$  = pressure differential across averaging Pitot tube in test section duct (Pa)

$\dot{Q}_{chem}$  = chemical heat release rate (kW)

$\dot{Q}_c$  = convective heat release rate (kW)

$T_a$  = average gas temperature in test section duct before ignition (K)

$T_d$  = gas temperature in test section duct (K)

TRP = thermal response parameter ( $kW \cdot sec^{1/2}/m^2$ )

$t$  = time (sec)

$\Delta t$  = time between data scans (sec)

$\dot{v}$  = total volumetric flow rate in test section duct ( $m^3/sec$ )

$W$  = horizontal width of a flat specimen or the circumference of a cable specimen (m)

$X_{CO_2}$  = measured carbon dioxide analyzer reading or mole fraction of carbon dioxide (—)

$X_{CO}$  = measured carbon monoxide analyzer reading or mole fraction of CO (—)

$y_s$  = mass of smoke particulates generated per unit mass of fuel vaporized (—)

*Superscripts*

$\cdot$  = per unit time ( $sec^{-1}$ )

0 = average value before ignition of the specimen

*Subscripts*

$d$  = test section duct

**1.5 Units.** The values stated in SI units shall be regarded as the standard.

## Chapter 2 Test Apparatus

### 2.1 General.

**2.1.1** When dimensions are stated in the text or in figures, they shall be considered mandatory and shall be followed within a tolerance of 0.5 percent. In addition to this tolerance, cylindrical components meant to fit together shall have a total clearance between the two components of 0.1 percent of the clearance diameter, 0.025 mm.

**2.1.2** The apparatus shall consist of the following components, shown in Figure 2.1.2: an infrared heating system, a load cell system, an ignition pilot flame and timer, a product gas analysis system, a combustion air distribution system, a water-cooled shield, an exhaust system, test section instruments, calibration instruments, and a digital data acquisition system.

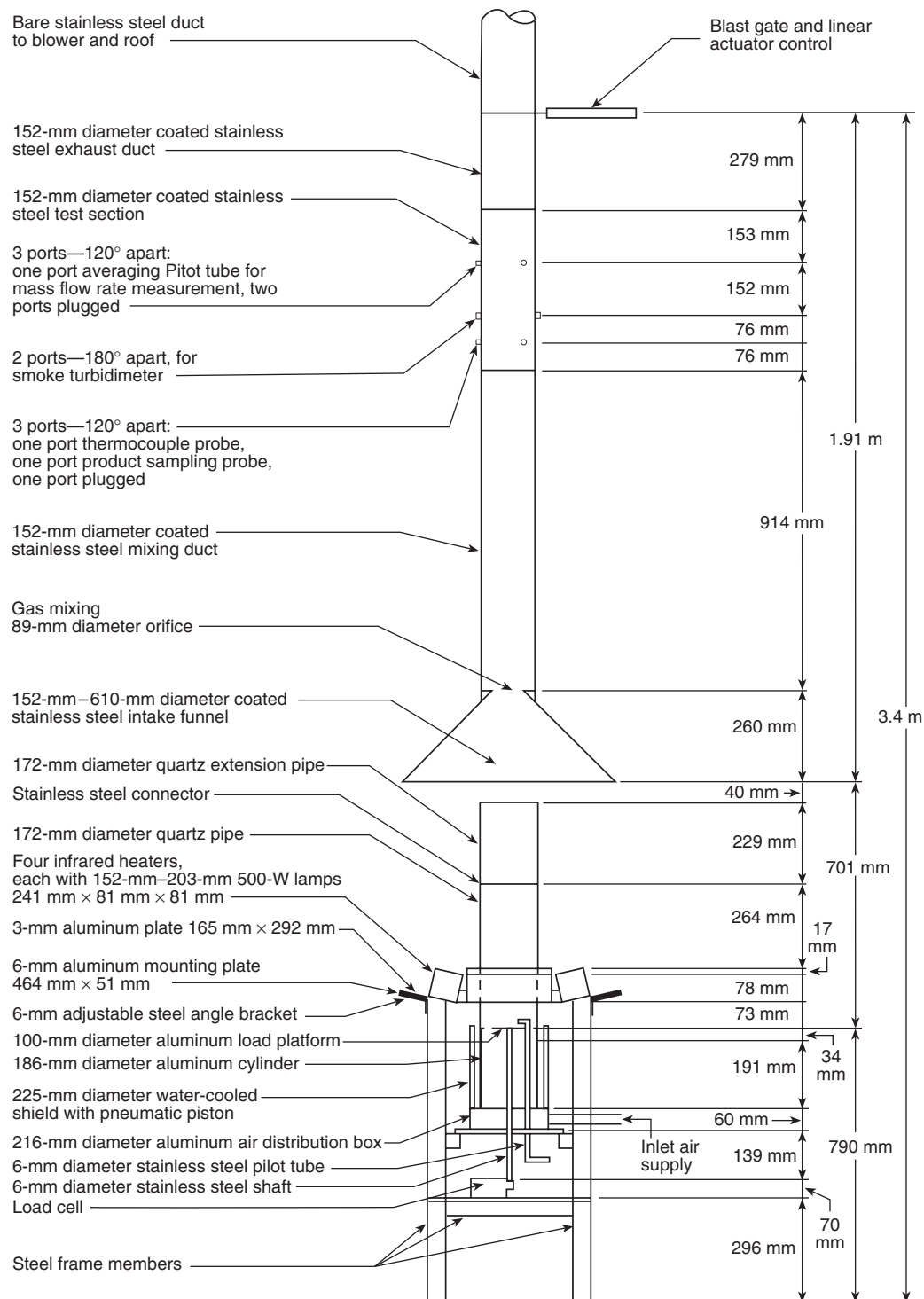
### 2.2 Infrared Heating System.

**2.2.1\*** Each of four 241-mm long infrared heaters shall contain six tungsten-filament tubular quartz lamps in a compact reflector body that, for a 120-volt input, shall produce  $190\ kW/m^2$  of radiant flux in front of the quartz window that covers the lamps. The emitter of each lamp shall be a 127-mm long tungsten filament in an argon atmosphere enclosed in a 9.5-mm outer-diameter clear quartz tube. The emitter shall operate at a minimum of 2475 K for a 120-volt input, to produce a spectral energy peak at 1.15 microns.

**2.2.2** The power controller shall maintain the output voltage required by the heater array despite variations in the line voltage and load impedance, through the use of phase angle power control to match the hot/cold resistance characteristics of the tungsten-quartz lamps. The controller also shall incorporate average voltage feedback to linearize the relationship between the voltage set by the operator and the output voltage to the lamps.



**FIGURE 2.1.2 Main view of apparatus.**

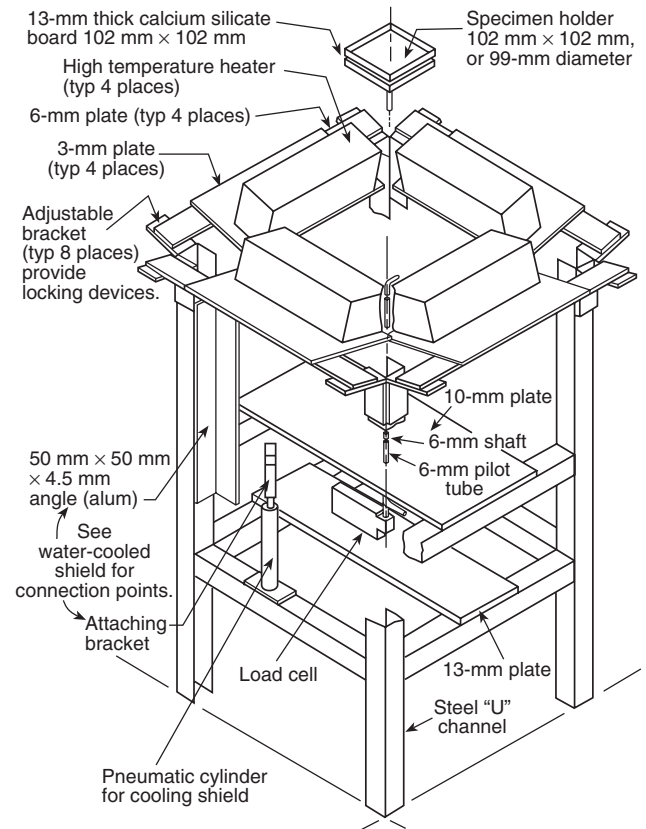


**2.3\* Load Cell System.** The load cell system, shown in Figures 2.3(a) and 2.3(b), shall consist of a load cell, which shall have an accuracy of 0.1 g and a measuring range of 0 to 1000 g; a 6.35-mm diameter stainless steel shaft at least 330 mm long resting on the load cell support point; a 100-mm diameter, 1.5-mm thick aluminum load platform connected to the upper end of the stainless steel shaft by a collar; and two low-friction, ball-bushing bearings that guide the shaft as it passes through the top and bottom, respectively, of the air distribution chamber. The stainless steel shaft shall incorporate, at the lower end, a threaded adjustment rod.

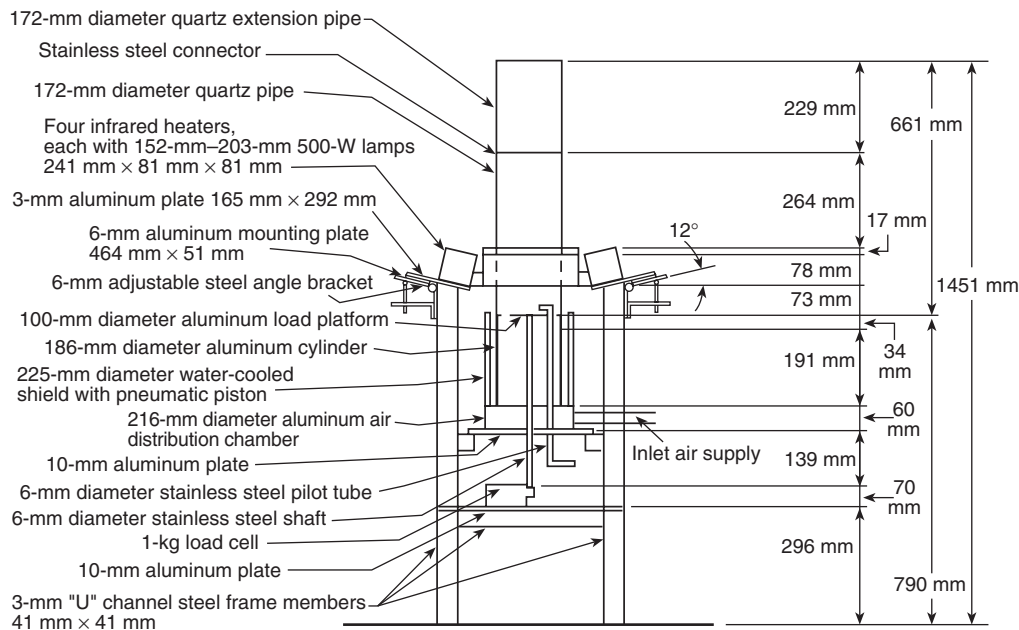
**2.4 Ignition Pilot Flame.** The ignition pilot shall consist of an ethylene-air (60–40 by volume) flame adjusted for a 10-mm length and anchored at the horizontal end of a 50-mm long, 6.35-mm outer diameter (O.D.), 4.70-mm inner diameter (I.D.), stainless steel tube. The horizontal section of the tube shall contain a four-hole ceramic insert to produce a stable flame and prevent flashback. The pilot flame tube shall be able to be rotated and elevated to position the horizontal flame at specified locations near the specimen, as shown in Figures 2.3(a) and 2.3(b).

**2.5 Ignition Timer.** The ignition timer for measuring time to sustained flaming shall be capable of recording elapsed time to the nearest tenth of 1 second and have an accuracy of better than 1 second in 1 hour.

**FIGURE 2.3(a) Exploded view of specimen mounting.**



**FIGURE 2.3(b) Main view of specimen mounting.**



## 2.6 Gas Analysis System.

**2.6.1** The gas-sampling arrangement, as shown in Figure 2.6.1, shall consist of a sampling probe in the test section duct, a plastic filter with a pore size of 5 to 6 microns to prevent entry of soot, a condenser operating at temperatures in the range of 5°C to 0°C to remove liquids, a tube containing an indicating desiccant 10-20 mesh in size to remove moisture, a cartridge filter, a sampling pump that transports the flow through the sampling line, and a system flowmeter and manifolds to direct the flow to individual CO, CO<sub>2</sub>, O<sub>2</sub>, and hydrocarbon gas analyzers. The sampling probe, made of 6.35-mm (0.25-in.) O.D. stainless steel tubing inserted through a test section port, shall be positioned so that the open end of the tube is at the center of the test section. The sampling probe shall be connected to a tee fitting that allows either sample or calibration gas to flow to the analyzer and the excess to waste.

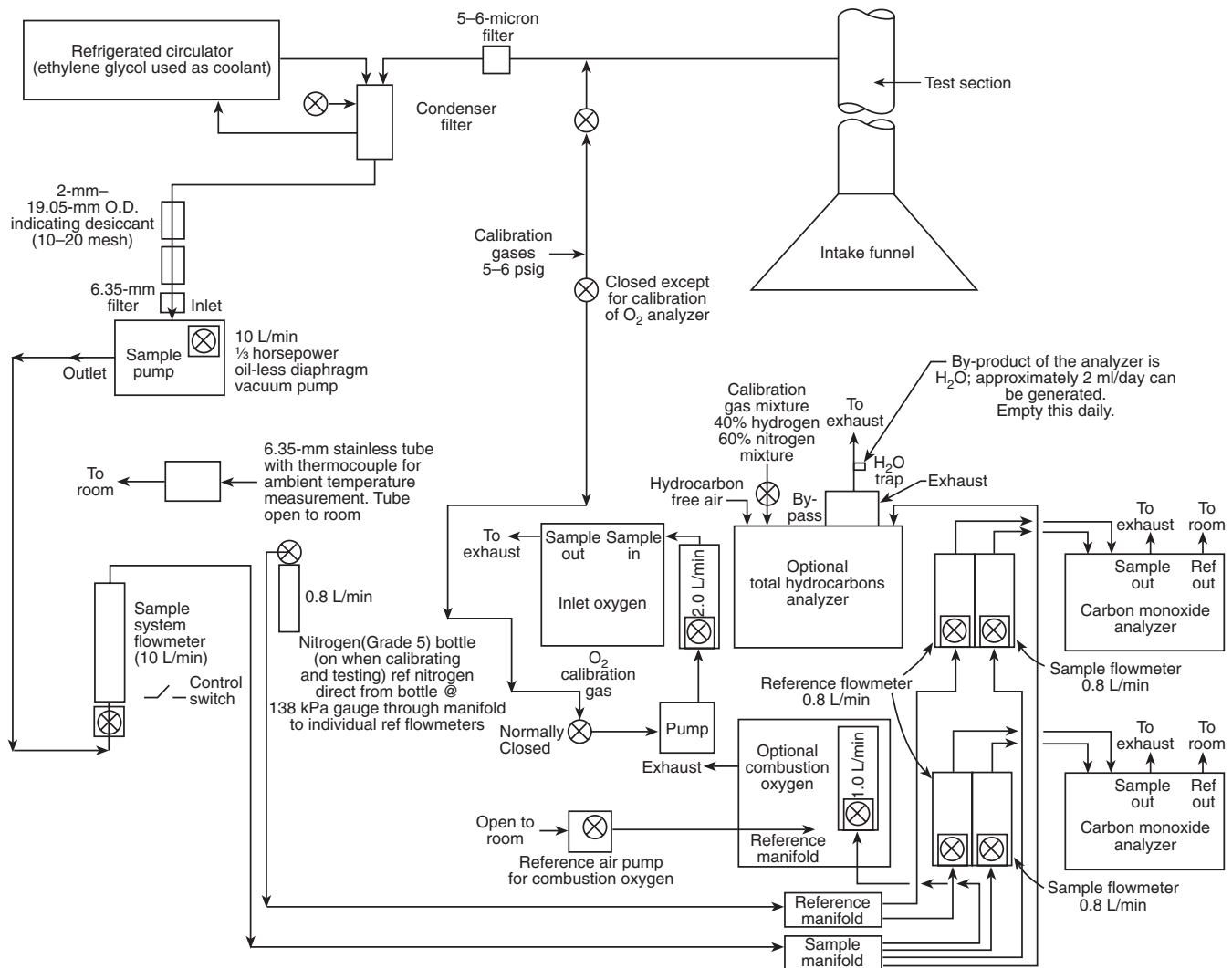
**2.6.2** The carbon dioxide analyzer shall permit measurements from 0 to 15,000 ppm, and the carbon monoxide analyzer shall permit measurements from 0 to 500 ppm concentration levels. Drift shall be not more than  $\pm 1$  percent of full scale over a

24-hour period. Precision shall be 1 percent of full scale, and the 10 percent to 90 percent of full-scale response time shall be 1.0 second or less.

**2.6.3** The inlet-air oxygen analyzer shall have a 10 percent to 90 percent of full-scale response time of 1.0 second or less, an accuracy of 1 percent of full scale, a drift of not more than  $\pm 50$  ppm  $O_2$  over one-half hour, and a range of 0 percent to 50 percent.

**2.6.4** An additional oxygen analyzer shall be permitted to measure the depletion of oxygen in the combustion products. This analyzer shall have the same specifications as the inlet-air analyzer but shall have a concentration range of 19 percent to 21 percent. A hydrocarbon gas analyzer shall be permitted to determine the total gaseous hydrocarbon concentration in the combustion products. This analyzer shall employ the flame ionization method of detection, have a 10 percent to 90 percent of full-scale response time of 1.0 second or less, and have multiple ranges to permit measurements from a full scale of 10 ppm methane equivalent to 10,000 ppm.

**FIGURE 2.6.1** Flow diagram of gas-sampling system.

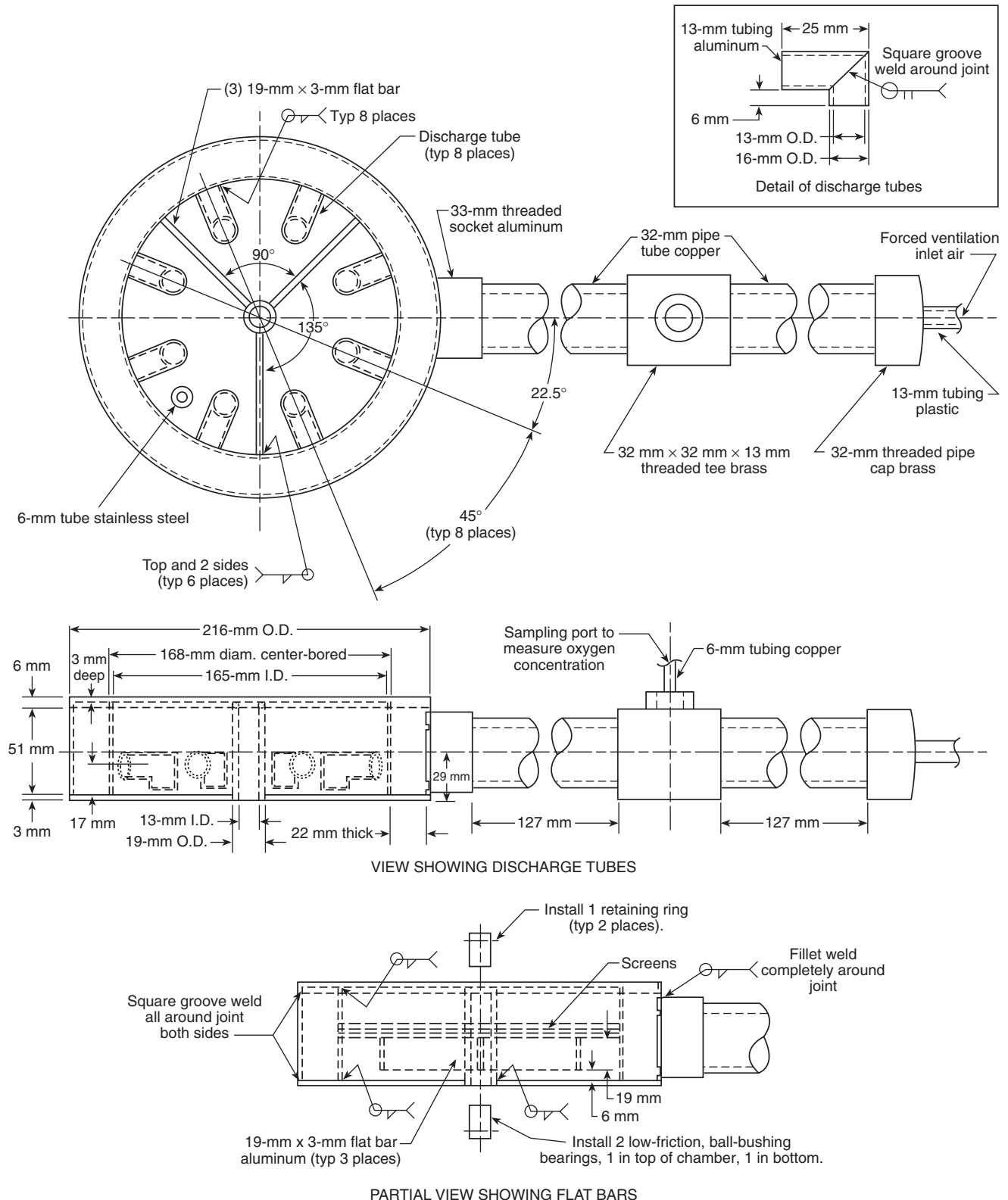


## 2.7 Combustion Air Distribution System.

2.7.1\* The aluminum air distribution chamber, shown in Figure 2.7.1, shall contain eight discharge tubes arranged in a circle of 165 mm I.D. Each tube shall be aluminum and built to

distribute inlet gases to three sets of screens, consisting of stainless steel woven wire cloth of 10, 20, and 30 mesh from bottom to top, respectively, for producing a uniform airflow.

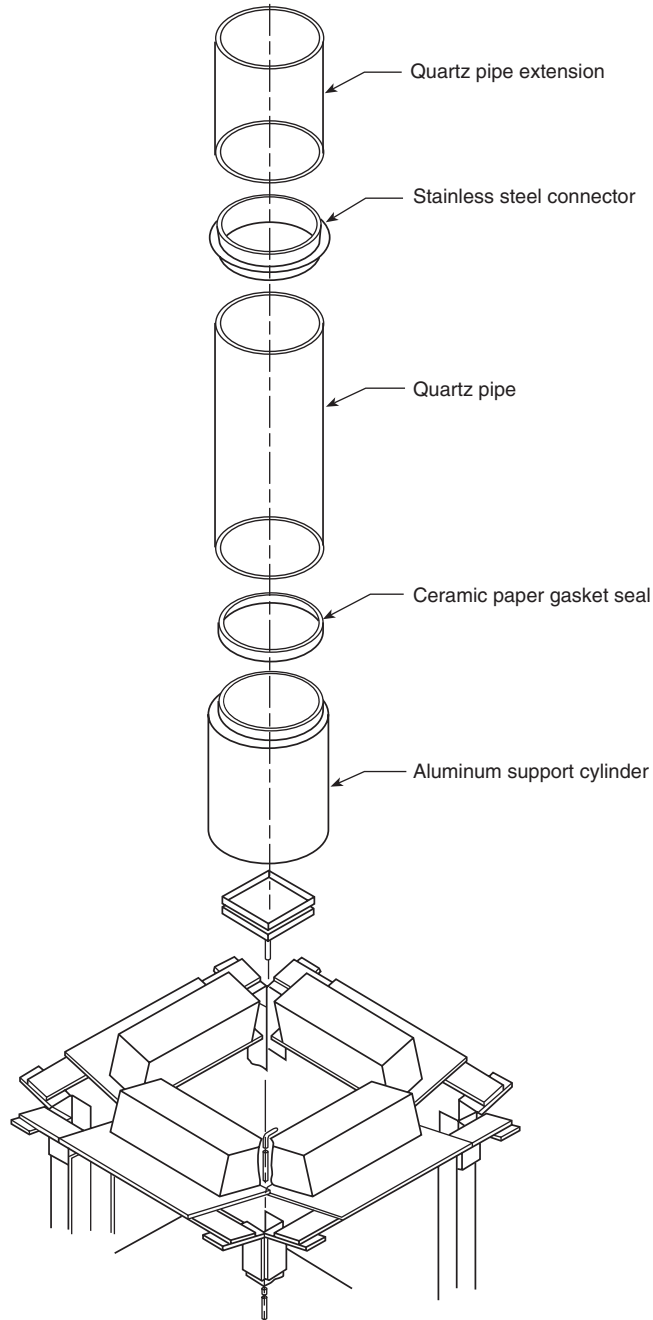
FIGURE 2.7.1 Air distribution chamber.

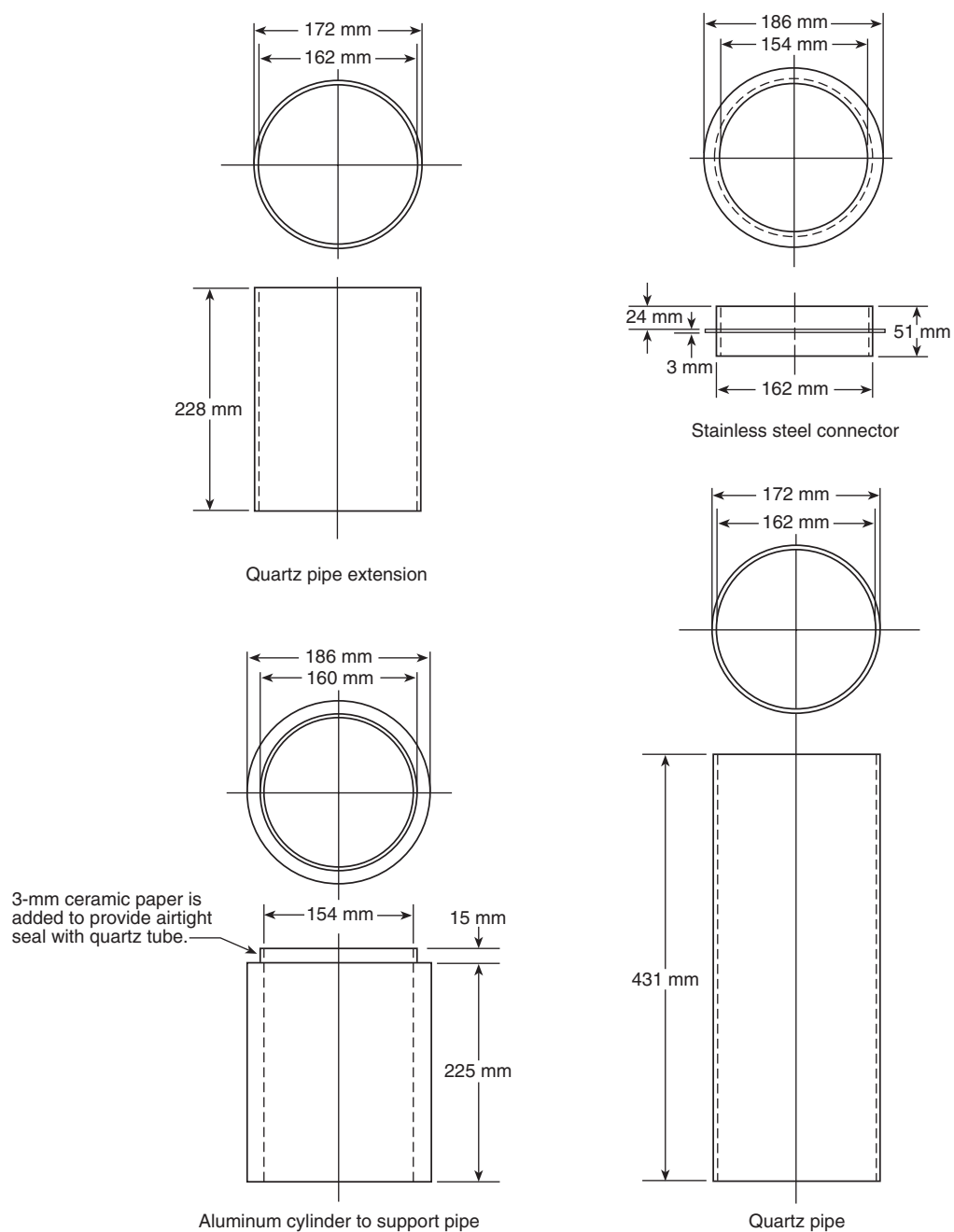


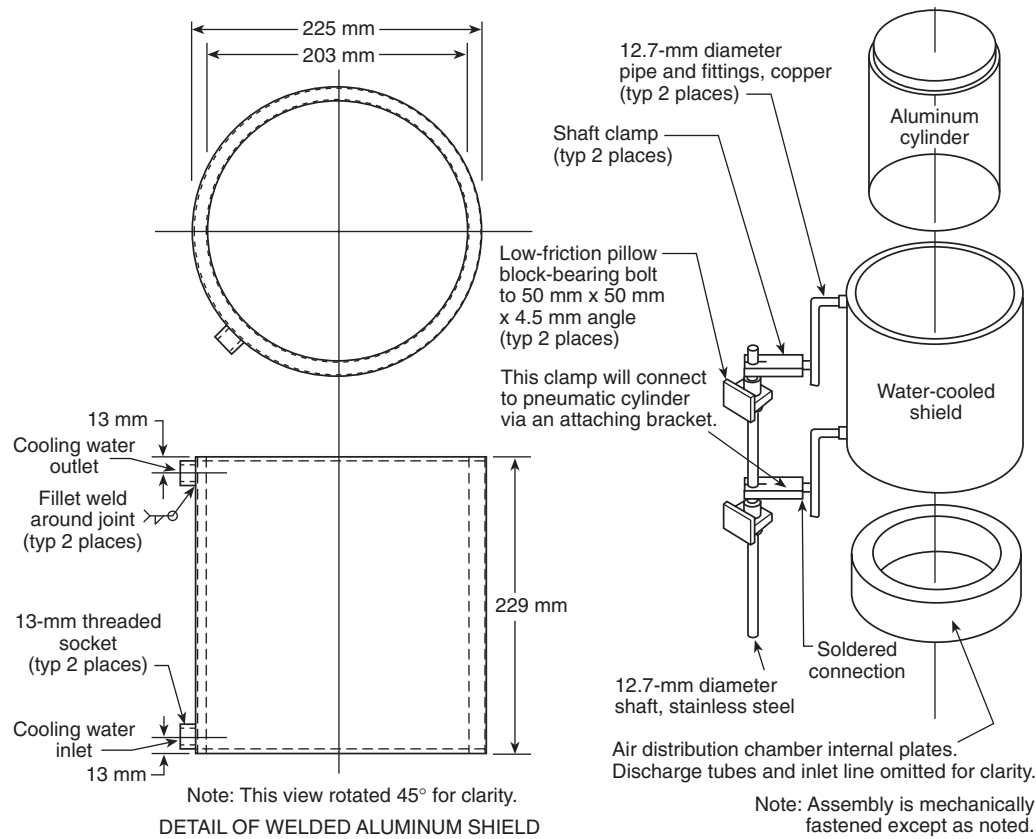
**2.7.2** The air supply pipes, shown in Figures 2.7.2(a) and 2.7.2(b), shall consist of an aluminum cylinder extending from the air distribution chamber up to the load platform. This cylinder shall contain a step to support a quartz pipe. Above the load platform elevation, the quartz pipe shall supply

oxidant to the specimen flame while allowing radiant energy from the infrared heating system to reach the specimen surface. The aluminum support cylinder shall be rigidly attached to the distribution chamber, with the quartz pipe removable.

**FIGURE 2.7.2(a) Exploded view of quartz pipe assembly.**

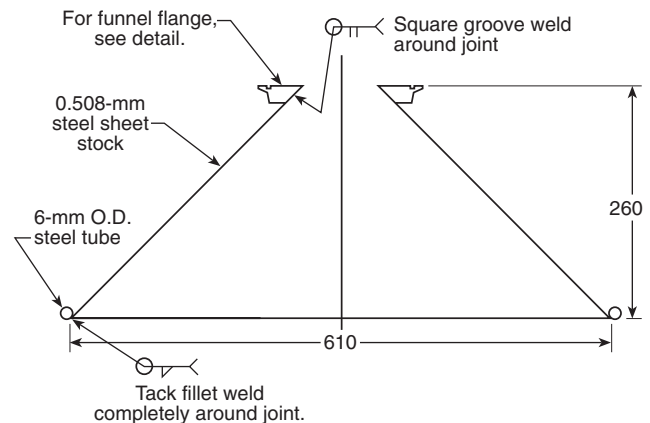


**FIGURE 2.7.2(b) Dimensions of quartz pipe assembly.**

**FIGURE 2.8 Water-cooled shield.**

**2.8 Water-Cooled Shield.** The water-cooled shield, shown in Figure 2.8, shall prevent the specimen from being exposed to the infrared heaters during the 1-minute heater stabilization period. The shield shall consist of two aluminum cylinders welded together with an inlet and outlet for water circulation. An electrically actuated pneumatic piston shall raise the shield to cover the specimen during test preparation and shall lower the shield within 1 second to expose the specimen at the start of a test.

**2.9 Exhaust System.** The exhaust system shall consist of the following main components: an intake funnel, as shown in Figures 2.9(a) and 2.9(b); a mixing duct, as shown in Figures 2.9(c) and 2.9(d); a test section, as shown in Figure 2.9(e); an exhaust duct, as shown in Figure 2.1.2; and a high-temperature blower to draw gases through the intake funnel, mixing duct, test section, and exhaust duct at flow rates from 0.1 to 0.3 m<sup>3</sup>/sec. The intake funnel, mixing duct, test section, and exhaust duct shall be coated internally with a fluorinated polyethylene-polypropylene (FEP) resin enamel and finish layers over a compatible primer, to form a three-layer coating that shall withstand temperatures of at least 200°C.

**FIGURE 2.9(a) Intake funnel.****Notes:**

- (1) All dimensions in mm unless noted
- (2) Inside of funnel to be coated with FEP after welding
- (3) Coat thickness: 0.5 mm

FIGURE 2.9(b) Funnel flange.

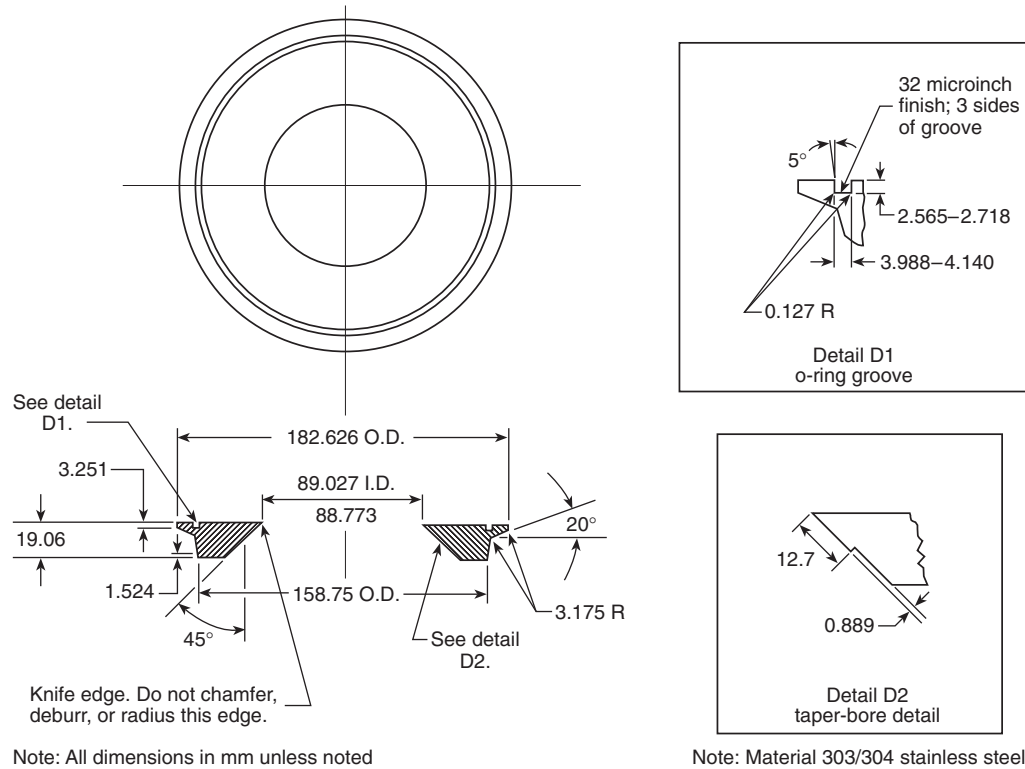


FIGURE 2.9(c) Mixing duct.

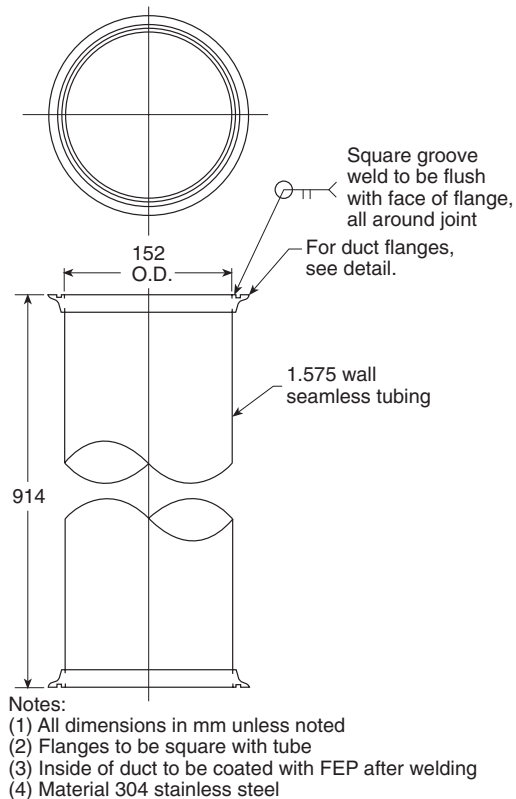
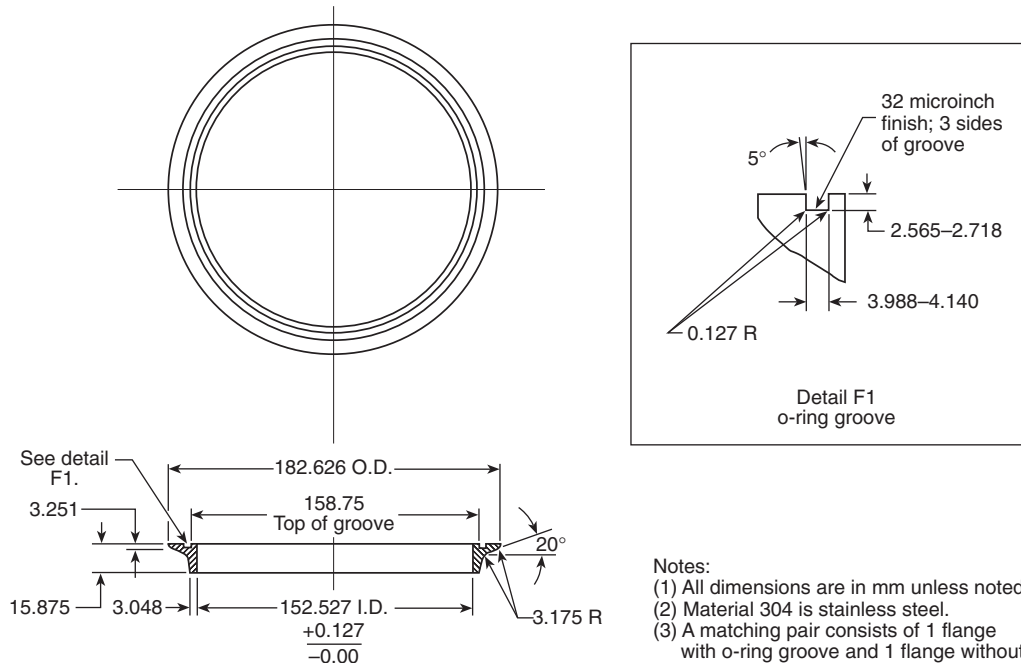




FIGURE 2.9(d) Duct flanges.



## 2.10 Test Section Instruments.

**2.10.1 Thermocouple Probe.** The thermocouple probe shall be inserted through a test section port and positioned so that the exposed, type K measurement bead is at the center of the test section, at the axial position of the gas-sampling port. The thermocouple probe shall be fabricated of wire no larger than 0.254 mm in diameter for measurement of gas temperature, with a time response in the specified exhaust flow of no more than 1 second and an accuracy of 1.0°C.

**2.10.2\* Averaging Pitot Probe and Pressure Transducer.** The averaging Pitot probe shall be inserted through a test section port 220 mm to 230 mm downstream of the thermocouple port and shall measure the mass flow rate of the gas stream by using at least four sets of flow-sensing openings. One set of openings shall face upstream, and the second set shall face downstream and be designed for compatibility with the test section diameter. The differential pressure generated by the probe shall be measured with an electronic pressure transducer (electronic manometer).

**2.10.3\* Smoke Turbidimeters.** The smoke turbidimeter measuring system, as shown in Figure 2.9(e), shall measure smoke extinction coefficient and both characteristic smoke particle size and particle number density. The interference filters shown in Figure 2.9(e) shall have the following specifications: central wavelengths of 457.9 nm, 632.8 nm, and 1064.0 nm,  $+2/-0$  nm; a filtering band width of 10 nm  $\pm$  2 nm; and minimum transmittance of 40 percent.

**2.11 Heat Flux Gauge.** The infrared heating system shall be calibrated by using a Gardon-type total heat flux gauge having a nominal range of 0 to 100 kW/m<sup>2</sup> and a flat, 6 mm to 8 mm in diameter sensing surface coated with a durable, flat-black finish. The body of the gauge shall be cooled by water above the dew point of the gauge environment. The gauge shall be rugged and maintain an accuracy of  $\pm 3$  percent and a repeatability within 0.5 percent between calibrations. Whenever the infrared heaters are calibrated, the calibration of the heat flux gauge shall be checked through the use of a black-body oven-calibration facility that compares the gauge response to that of an optical pyrometer with a NIST-traceable calibration, or through the use of a facility that compares the gauge output to that of a reference standard.

**2.12 Digital Data Collection.** The digital data collection system shall be capable of recording the output from the CO, CO<sub>2</sub>, hydrocarbon gas, O<sub>2</sub> combustion, and O<sub>2</sub> inlet air analyzers, the load cell, the test section instruments, and the electronic pressure transducer at 1-second intervals. The data for gas concentrations shall be time-shifted to account for delays within the gas-sampling lines and respective instrument response times. The data collection system shall have an accuracy corresponding to at least  $\pm 1^\circ\text{C}$  for temperature measurement and  $\pm 0.01$  percent of full-scale instrument output for all other channels. The system shall be capable of recording data for at least 1 hour at 1-second intervals.

Ribbon filament lamp

Pinhole

Rear collimating lens

Optical path

149 mm

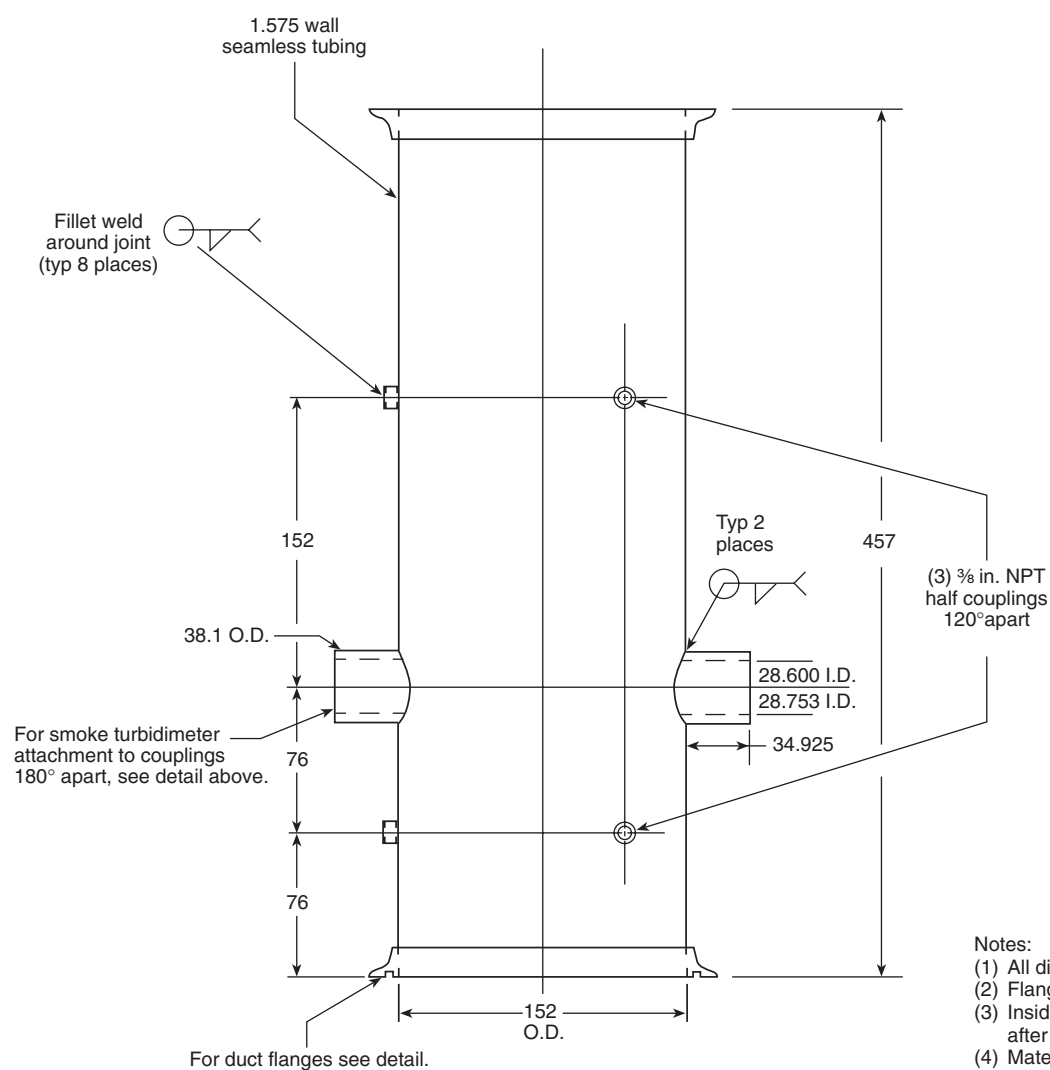
12.7 I.D. smoke diffusion tube

Cube beam splitter

Interference filter

Photodetector

SMOKE TURBIDIMETER



## Chapter 3 Calibration of Equipment

### 3.1 Radiant Flux Heater.

**3.1.1** Infrared heaters shall be calibrated at the start of the test day. The quartz windows, lamps, and back reflective surfaces of the heaters shall be cleaned of any impurity buildup or scratches. The sensing surface of the heat flux gauge shall be positioned to be horizontal, at a location equivalent to the center of the top surface of a horizontal specimen. Calibrations shall be performed, both with and without the quartz pipe in position, by recording infrared heater voltage settings and corresponding heat flux gauge outputs that cover the entire range of flux levels for planned tests.

**3.1.2** At least annually, the position of the infrared heaters shall be checked by setting the heater voltage at 90 percent of the maximum value, positioning the heat flux gauge sensing surface to be horizontal, and measuring the heat flux at each of five locations, corresponding to each corner and the center of a square, horizontal specimen, at an elevation equivalent to that of the specimen top surface. The position of each infrared heater shall be adjusted symmetrically, and the heat flux measurements repeated until there is at most a 5 percent mean deviation of the five readings from the average value. Then, the heat flux gauge shall be positioned, with the sensing surface horizontal, to locations equivalent to the vertical axis at the center of a square, horizontal specimen, and the heat flux measured at elevations of 10 mm and 20 mm above and below that equivalent to the specimen top surface. The heat flux at these four elevations shall be checked to ensure that it is within 5 percent of the value at the elevation of the specimen top surface.

### 3.2 Gas Analysis Equipment.

**3.2.1** The gas analysis equipment shall be calibrated before the first combustion or fire propagation test of the day.

**3.2.2** Carbon dioxide and carbon monoxide analyzers shall be calibrated for measurement of the combustion gases by establishing a downscale/zero calibration point and an upscale/span calibration point. The upscale calibration shall be performed with a “span gas” at the upper end of the range that will be used during actual sample analysis and with a “zero gas” for the downscale calibration point at the lower end of the analyzer range. Nitrogen shall be used as the “zero gas” reference source by turning on a cylinder of Grade 5 nitrogen.

**3.2.3** The oxygen analyzer for the measurement of inlet oxygen concentration and the optional oxygen analyzer for the measurement of combustion gases shall be calibrated by establishing a downscale/zero calibration point and an upscale/span calibration point. The upscale calibration shall be performed with a “span gas” at the upper end of the range that will be used during actual sample analysis and with a “zero gas” for the downscale calibration point at the lower end of the analyzer range. Grade 5 nitrogen shall be used as the “zero gas” reference source. The optional combustion gas oxygen analyzer shall be checked to ensure that the span (upper range) setting does not change by more than 0.1 percent after the first zero gas (downscale) setting is performed. If it does change by more than this amount, then the calibration procedure shall be repeated.

**3.2.4** The optional hydrocarbon gas analyzer shall be calibrated at the downscale point by using Grade 5 nitrogen as the “zero gas.” Methane at a concentration that matches the operating range of the analyzer shall be used as the “span gas” for the upscale calibration.

**3.3 Load Cell.** The load cell shall be calibrated each time it is used. The output voltage shall be set to zero by adjusting the tare, with the appropriate empty specimen holder in position. A NIST-traceable weight corresponding to the weight of the specimen to be tested shall then be placed on the empty holder, and the output voltage shall be measured. Linearity shall be checked by repeating this procedure with three other NIST-traceable weights so as to cover the entire specimen weight range.

### 3.4 Heat Release Calibration.

**3.4.1\*** The heat release rate measurement process shall be calibrated at least monthly to ensure the proper functioning of the fire propagation apparatus. The measured effective heat of combustion of acetone shall be checked to ensure that it is within 5 percent of the reference value of 27,900 kJ/kg and that the measured total delay (or lag) time of the gas analyzers is less than 15 seconds.

**3.4.2** The infrared heaters or the pilot shall not be used.

**3.4.3** All other required calibration procedures described in Section 3.4 shall be performed.

**3.4.4** Inlet airflow shall be checked to ensure that it is set at  $200 \pm 20$  L/min.

**3.4.5** The data acquisition program shall be started.

**3.4.6** Acetone in the amount of 100.0 ml shall be placed in a 97-mm diameter heat-resistant glass specimen dish on the load cell.

**3.4.7** The acetone shall be ignited using a match 30 seconds after the start of data acquisition.

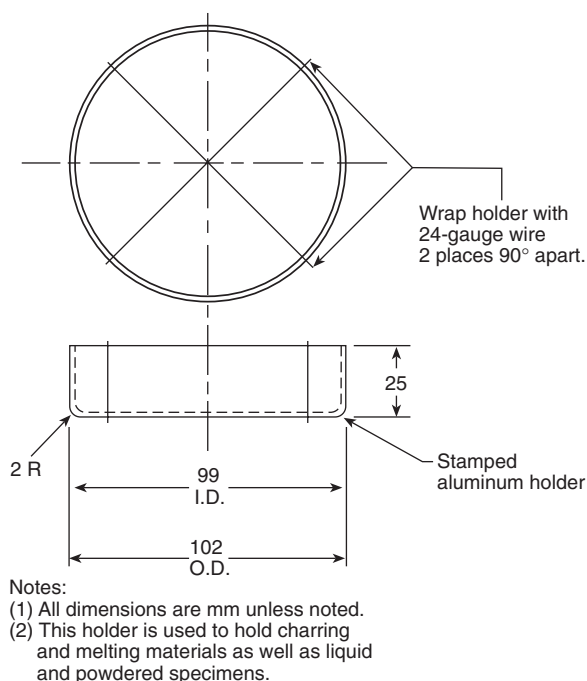
**3.4.8** Data acquisition shall be ended 2 minutes after the end of visible flaming.

**3.4.9** The effective heat of combustion shall be determined in accordance with the calculation procedure in Section 6.4.

**3.4.10** The delay time for the gas analyzers shall be determined by computing the difference between the time when the test section duct gas temperature reaches 50 percent of its steady-state value and the time when the reading of each analyzer reaches 50 percent of its steady-state value.

## Chapter 4 Test Specimens

**4.1 Specimen Holders.** Four types of specimen holders shall be permitted: horizontal square; horizontal circular, as shown in Figure 4.1 (a); vertical, as shown in Figure 4.1 (b); and vertical cable, as shown in Figure 4.1 (c). The horizontal square holder shall consist of two layers of “2 mil” (0.05-mm thickness) aluminum foil molded to the sides and bottom of a square specimen. The horizontal circular holder shall be a 99-mm diameter aluminum dish. The vertical specimen holder shall be a 485-mm high  $\times$  133-mm wide ladder rack. The vertical cable holder shall be 825 mm high, for supporting a cable specimen 810 mm long and up to 51 mm in diameter.

**FIGURE 4.1(a) Horizontal circular specimen holder.**

**4.2 Conditioning.** Specimens shall be conditioned, before surface preparation or testing, to moisture equilibrium at a temperature of  $23 \pm 3^\circ\text{C}$  and a relative humidity of  $50 \pm 5$  percent for 24 hours.

#### 4.3 Specimen Size and Preparation.

**4.3.1\* Ignition and Combustion Tests of Horizontal Specimens.** Specimens for the horizontal square holder shall be cut from planar materials or products to be  $101.6 \text{ mm} \times 101.6 \text{ mm}$  in area. Square specimens shall have a thickness of no less than 3 mm and no more than 25.4 mm. For materials and products having a thickness greater than 25.4 mm, the unexposed surface shall be cut to reduce the thickness to 25.4 mm. When the ignition test is paired with a fire propagation test, the specimen thickness shall be identical in both tests.

Square specimens shall be used with the horizontal square holder.

Granular specimens shall be used with the horizontal circular holder by filling the aluminum dish. Cable specimens shall be used with the horizontal circular holder, by cutting them to cover the center and at least 20 mm on each side of the center of the aluminum dish. The exposed top surface of square, granular, and cable specimens shall be sprayed with a single coat of flat black paint that is designed to withstand temperatures up to  $540 \pm 10^\circ\text{C}$ . The paint coating shall be cured by conditioning the specimen at a temperature of  $23 \pm 3^\circ\text{C}$  and a relative humidity of  $50 \pm 5$  percent for 48 hours. Before testing, the holder containing the specimen shall be placed on a 13-mm thick calcium silicate board having a density of  $700 \text{ kg/m}^3$  to  $750 \text{ kg/m}^3$ , a thermal conductivity of  $0.11 \text{ W/mK}$  to  $0.13 \text{ W/mK}$ , and the same dimensions as the holder, as shown in Figure 2.3(a).

**4.3.2 Fire Propagation Test of Vertical Specimens.** Vertical specimens shall be cut from planar materials or products to be 101.6 mm in width and 305 mm in height. Vertical specimens shall have a thickness of no less than 3 mm and no more than 13 mm. For materials and products having a thickness greater than 13 mm, the unexposed surface shall be cut to reduce the thickness to 13 mm. When the fire propagation test is paired with an ignition test, the specimen thickness shall be identical in both tests.

Ceramic paper having a density  $190 \text{ kg/m}^3$  to  $200 \text{ kg/m}^3$  and a thickness of 3.2 mm shall be placed to cover the sides and back surface of the vertical specimen. Two layers of "2 mil" (0.05 mm) thickness aluminum foil shall then be molded to the ceramic paper on the sides and back surface of the vertical specimen, thereby leaving the front surface of the specimen exposed for testing. Following this preparation, the bottom of the vertical specimen shall be placed on the metal baseplate of the vertical holder shown in Figure 4.1(b), with the covered (back) surface of the specimen against the ladder rack. To secure the specimen to the vertical specimen holder, 24 gauge nickel-chromium wire shall be wrapped three turns around the vertical specimen, the ladder rack, and the threaded rods, at distances of 100 mm and 200 mm from the bottom of the specimen.

Cable specimens shall be mounted as shown in Figure 4.1(c).

**4.4 Mounting Methods.** The exact mounting and retaining methods used shall be specified in the test report if different from the techniques in Section 4.3.

**FIGURE 4.1(b) Vertical specimen holder.**

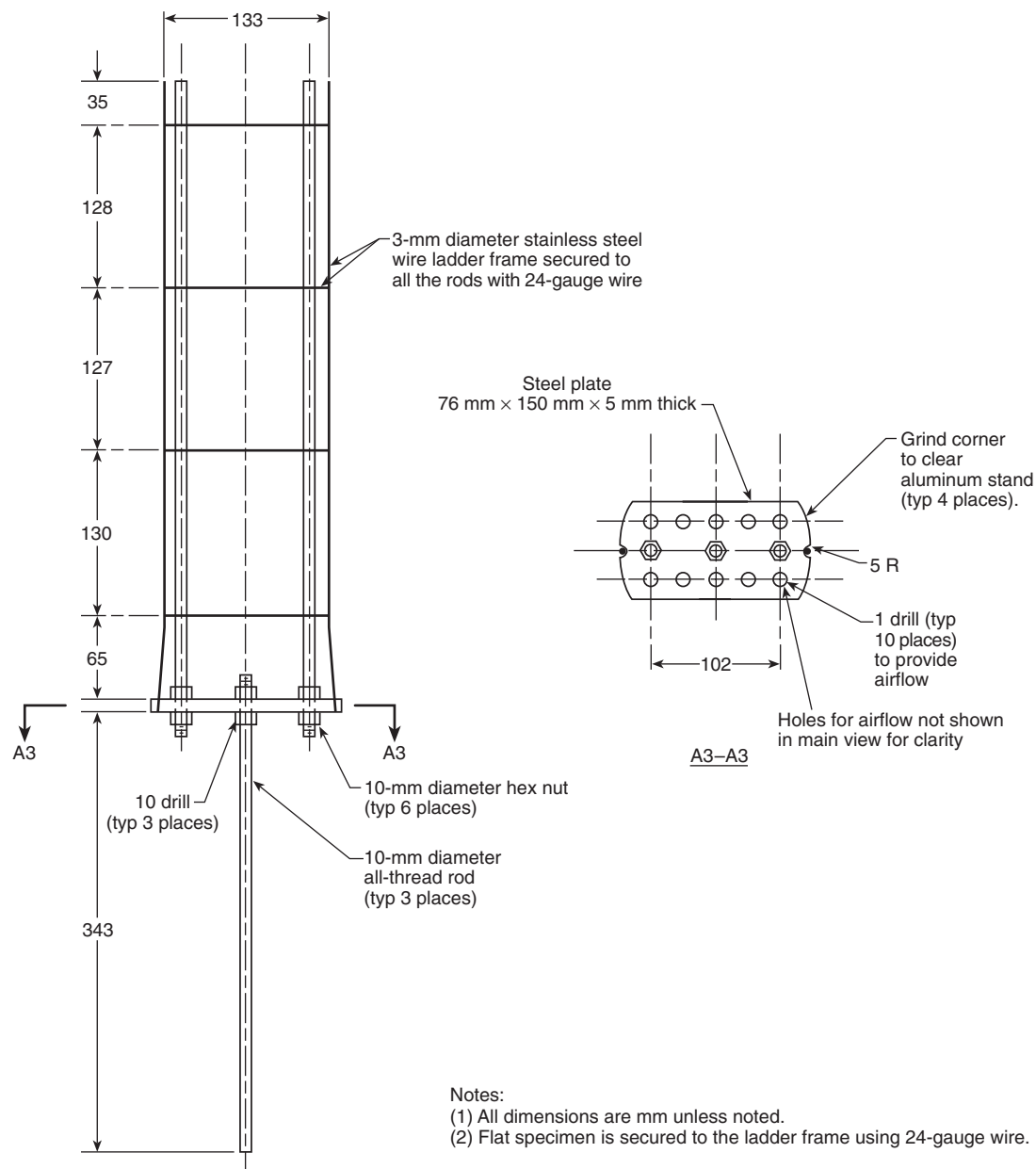
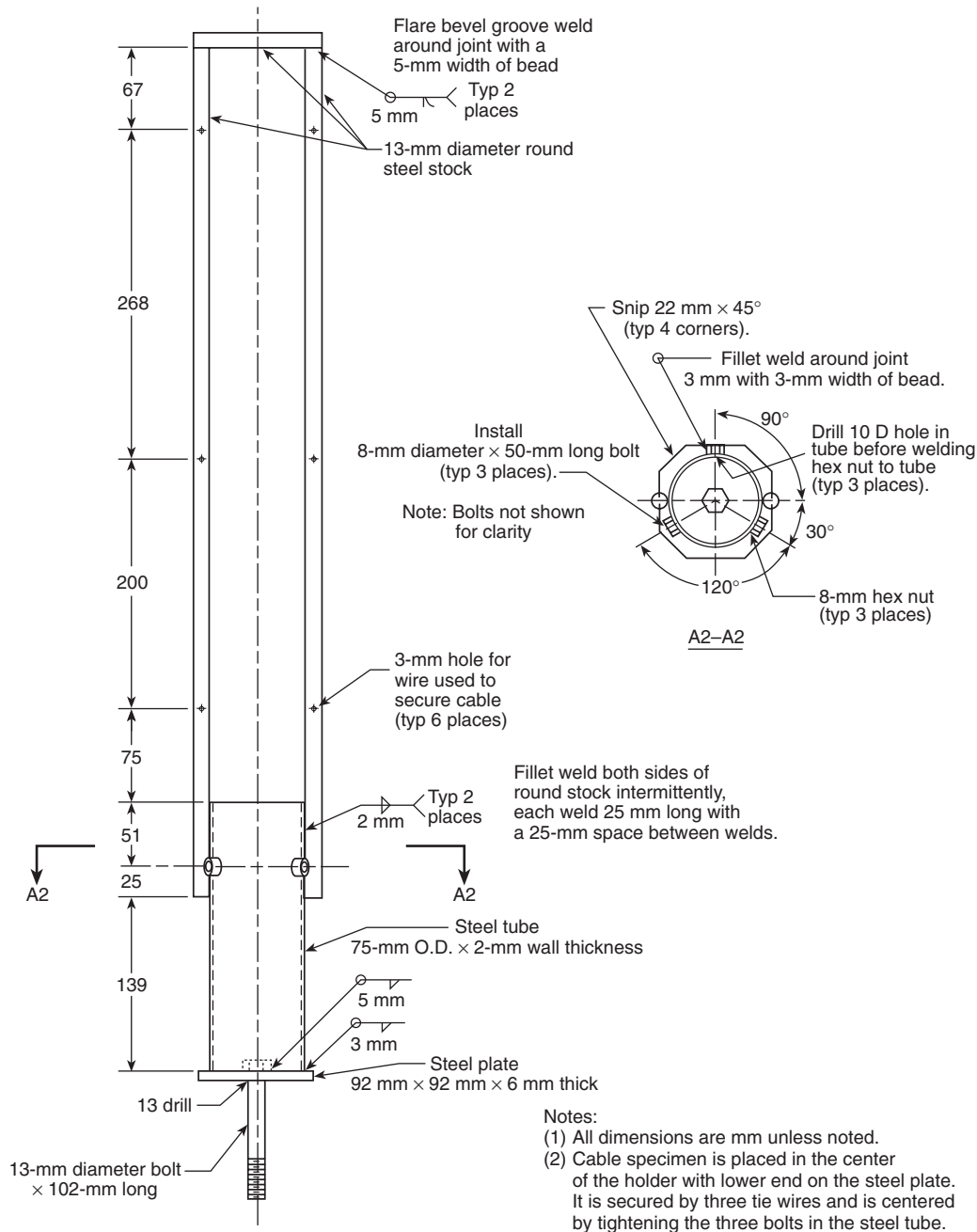


FIGURE 4.1(c) Cable specimen holder.



## Chapter 5 Test Procedure

**5.1 Procedure 1: Ignition Test.** The ignition test shall be performed to determine the TRP, and the CHF of a material, through measurement of the ignition time over a range of external heat fluxes.

**5.1.1** Nitrogen for extinguishing flames shall be ready to flow at  $100 \pm 10$  L/min, and cylinders of compressed ethylene and air shall be available to give the specified pilot flame when needed.

**5.1.2** The 13-mm thick calcium silicate board supporting the appropriate horizontal specimen holder shall be centered on the aluminum load platform with no quartz pipe in place, to ensure natural airflow.

**5.1.3** The exhaust blower shall be turned on.

**5.1.4** The pilot flame shall be ignited and adjusted for a 10-mm flame length.

**5.1.5** The lighted pilot flame shall be moved to a position 10 mm above the specimen surface and 10 mm radially from the perimeter of the specimen.

**5.1.6** The air and water supplies shall be turned on to cool the infrared heaters.

**5.1.7** The water-cooled shield surrounding the specimen holder shall be raised to prevent specimen exposure to external heat flux.

**5.1.8** The infrared heater voltage shall be set to produce a 30-kW/m<sup>2</sup> exposure on the specimen surface, and the infrared heater shall be allowed to stabilize for 1 minute.

**5.1.9** The water-cooled shield shall be lowered to expose the sample to the external heat flux, and the ignition timer shall be started.

**5.1.10** The time at the first appearance of vapors from the specimen shall be recorded and the time to ignition shall be recorded as the time from exposure to the external heat flux until a sustained flame is established for at least a 4-second duration.

**5.1.11** Nitrogen shall be introduced to extinguish flames.

**5.1.12\*** The specimen shall be removed to a ventilated environment.

**5.1.13** The procedures of 5.1.1 to 5.1.12 shall be repeated for infrared heater settings of 35, 40, 45, 50, 55, and 60 kW/m<sup>2</sup>. If the specimen ignites at 30 kW/m<sup>2</sup> within 15 minutes, the same procedure shall be repeated at 25, 20, 15, and 10 kW/m<sup>2</sup>, in that order, until there is no ignition for 15 minutes.

**5.2 Procedure 2: Combustion Test.** The combustion test shall be conducted to determine the EHC and the  $y_s$ , and to measure the chemical and convective heat release rates ( $\dot{Q}_{chem}$  and  $\dot{Q}_c$ ).

**5.2.1** The gas-sampling system shall be removing all water vapor and other condensable combustion products. If the sampling system flowmeter indicates a flow of less than 10 L/min, then the sampling system filter elements shall be replaced.

**5.2.2** Fresh indicating desiccant and a soot filter shall be installed in the gas-sampling line.

**5.2.3** The flame in the hydrocarbon gas analyzer shall be ignited, and the flame-out indicator on the front panel shall be checked to ensure that there is flame ignition.

**5.2.4** Nitrogen for extinguishing flames shall be ready to flow at 100 ± 10 L/min, and cylinders of compressed ethylene and air shall be available to produce the specified pilot flame when needed.

**5.2.5** The gas-sampling pump to oxygen, carbon monoxide, carbon dioxide, and hydrocarbon gas analyzers shall be turned on, and correct flow rates shall be set for each instrument. Gas analyzers shall be powered on at all times to maintain constant internal temperatures.

**5.2.6** The required calibration procedures shall be performed, as specified in Chapter 3.

**5.2.7** The exhaust and air supply blowers servicing the apparatus shall be turned on.

**5.2.8** The 13-mm thick calcium silicate board supporting the appropriate horizontal specimen holder shall be centered on the aluminum load platform.

**5.2.9** The pilot flame shall be ignited and adjusted for a 10-mm flame length.

**5.2.10** The lighted pilot flame shall be moved to a position 10 mm above the specimen surface and 10 mm radially in from the perimeter of the specimen.

**5.2.11** The air and water supplies shall be turned on to cool the infrared heaters.

**5.2.12** The quartz pipe shall be installed on the mounting step in the aluminum oxidant supply pipe.

**5.2.13** The water-cooled shield surrounding the specimen holder shall be raised to prevent exposing the specimen to the external heat flux.

**5.2.14** The inlet airflow shall be set at 200 ± 20 L/min and the exhaust flow rate set at 0.25 ± 0.025 m<sup>3</sup>/sec.

**5.2.15** The infrared heater voltage shall be set to expose the specimen surface to 50 kW/m<sup>2</sup> and shall be allowed to stabilize for 1 minute.

**5.2.16** The data acquisition system shall be started.

**5.2.17** Thirty to 35 seconds after the start of data acquisition, the water-cooled shield shall be lowered to expose the specimen to the infrared heaters.

**5.2.18** The following shall be recorded: the time at the first appearance of vapors from the specimen, the time at ignition, the flame height, the flame color and smokiness, any unusual flame behavior, and the time at flame extinction.

**5.2.19** If flames reach 35 ± 10 mm above the rim of the collection funnel for more than 30 seconds, they shall be extinguished by introducing nitrogen.

**5.2.20** Data acquisition shall be continued for a period of 2 minutes after specimen flaming has ceased.

**5.2.21** The specimen shall be removed from the specimen holder and weighed, and the residue mass shall be recorded when the specimen has cooled.

**5.2.22** The procedures of 5.2.1 through 5.2.21 shall be repeated to give at least three determinations of the heat release rate, mass loss rate, and smoke yield.

**5.3 Procedure 3: Fire Propagation Test.** The fire propagation test shall be performed to determine the FPI of a material, through measurement of the chemical heat release rate of a vertical specimen during and after upward fire propagation.

**5.3.1** The procedures of 5.2.1 through 5.2.7 for measurement of heat release rate, with the exception of the load cell calibration, shall be repeated.

**5.3.2** The stainless steel load cell shaft and the ball-bushing bearings in the air distribution chamber shall be removed and replaced with the appropriate vertical specimen holder, and the specimen shall be installed, so that the bottom edge of the vertical specimen that is to be exposed to external heat flux is at an elevation equivalent to that of the top surface of a horizontal specimen.

**5.3.3** The pilot flame shall be ignited and adjusted for a 10-mm flame length.

**5.3.4** The exhaust and air supply blowers servicing the apparatus shall be turned on, and a cylinder of Grade 2.6 oxygen shall be connected to the inlet air supply line.

**5.3.5** The air and water supplies shall be turned on to cool the infrared heaters.

**5.3.6** The quartz pipe shall be installed on the mounting step in the aluminum oxidant supply pipe.

**5.3.7** The water-cooled shield surrounding the specimen holder shall be raised to prevent exposing the specimen to the external heat flux.

**5.3.8** The pilot flame shall be moved to a position 75 mm above the bottom of the specimen and 10 mm away from the specimen surface.

**5.3.9** The inlet air/oxygen flow shall be set at  $200 \pm 20$  L/min, the inlet oxygen concentration at 40 percent, and the exhaust flow rate at  $0.25 \pm 0.025$  m<sup>3</sup>/sec.

**5.3.10** The infrared heater voltage shall be set to produce 50 kW/m<sup>2</sup> and allowed to stabilize for 1 minute.

**5.3.11** The data acquisition program shall be started.

**5.3.12** Thirty to 35 seconds after the start of data acquisition, the water-cooled shield shall be lowered to expose the lower portion of the vertical specimen to the infrared heaters, and the ignition timer shall be started.

**5.3.13** The base area of the specimen shall be preheated for 1 minute. If ignition and fire propagation have not already occurred, the pilot flame shall be moved into contact with the specimen surface 75 mm above the bottom of the specimen to initiate fire propagation. The pilot flame shall then be moved away from the specimen.

**5.3.14** The chemical heat release rate shall be measured as a function of time during and after fire propagation, using the combustion test procedures.

**5.3.15** The following shall be recorded: the time at the first appearance of vapors from the specimen, the time at ignition, the flame height at 1-minute intervals, the flame color and smokiness, any unusual flame behavior, and the time at flame extinction.

**5.3.16** The test shall be terminated 2 minutes after the end of visible flaming or if flames reach  $35 \pm 10$  mm above the rim of the collection funnel for more than 30 seconds or if the specimen undergoes noticeable structural deformation.

**5.3.17** The procedures of 5.3.1 through 5.3.16 shall be repeated to give at least three heat release rate determinations.

**5.4 Safety Precautions.** All normal laboratory safety precautions shall be followed.

**5.4.1\*** During the test, the operator shall use hearing protection and at least shade 5 welding goggles or glasses. The operator shall use protective gloves to insert and remove test specimens. The specimen residue shall be transferred to a fume hood. Neither the infrared heaters nor the associated fixtures shall be touched while hot except with protective gloves.

**5.4.2** The exhaust shall be checked for proper operation before testing and shall be discharged away from intakes for the building ventilation system. Provision shall be made for collecting and venting any combustion products that fail, for whatever reason, to be collected by the normal exhaust system of the apparatus.

## Chapter 6 Calculations

**6.1 Critical Heat Flux (CHF).** The CHF shall be the intercept with the ordinate of a straight-line regression fit to data on external heat flux (from the infrared heaters) versus the inverse of time to ignition. Data shall be from the four lowest values for heat flux (e.g., 30, 25, 20, and 15 kW/m<sup>2</sup>) in the ignition test. The standard deviation (or standard error) of the intercept due to data scatter shall be within 10 percent of the regression fit intercept. Additional data shall be obtained if the standard deviation exceeds this limit.

**6.2 Thermal Response Parameter (TRP).** The TRP shall be the slope of a straight-line regression fit to data on external heat flux (from the infrared heaters) versus the inverse of the square root of the time to ignition. Data shall be from the four highest values for external heat flux (e.g., 45, 50, 55, and 60 kW/m<sup>2</sup>) in the ignition test. The standard deviation (or standard error) of the slope due to data scatter shall be within 10 percent of the regression fit slope. Additional data shall be obtained if the standard deviation exceeds this limit.

### 6.3 Fire Propagation Index (FPI).

**6.3.1** The FPI shall be determined from the fire propagation and ignition tests by using the following equation:

$$FPI = \frac{1000(0.42 \dot{Q}_{chem}/W)^{1/3}}{TRP}$$

where  $\dot{Q}_{chem}$  shall be obtained from the fire propagation test and TRP from the ignition test.

**6.3.2** The chemical heat release rate shall be determined from the following equation:

$$\dot{Q}_{chem} = 13,300(\dot{G}_{CO_2} - \dot{G}_{CO_2}^0) + 11,100(\dot{G}_{CO} - \dot{G}_{CO}^0)$$

**6.3.3** The mass flow rates of CO<sub>2</sub> and CO shall be determined from the following equations:

$$\dot{G}_{CO_2} = A_d K \left( \frac{P_{atm}}{101,000} \right)^{1/2} \left[ 2 \left( \frac{353 \Delta p_m}{T_d} \right) \right]^{1/2} (0.152 X_{CO_2})$$

$$\dot{G}_{CO} = A_d K \left( \frac{P_{atm}}{101,000} \right)^{1/2} \left[ 2 \left( \frac{353 \Delta p_m}{T_d} \right) \right]^{1/2} (0.966 X_{CO})$$

where 353 (kg K/m<sup>3</sup>) is the product of air density and temperature at normal atmospheric pressure.

**6.4 Effective Heat of Combustion (EHC).** The EHC shall be determined from the following equation:

$$EHC = \frac{\Sigma \dot{Q}_{chem} \Delta t_i}{M_{loss}}$$

where the summation shall be taken over all combustion test data scans and  $\dot{Q}_{chem}$  shall be obtained from 6.3.2 and 6.3.3.



### 6.5 Smoke Yield ( $y_s$ ).

**6.5.1** The three values for  $y_s$  corresponding to each of the three turbidimeter wavelengths ( $\lambda$ ) shall be determined from the following equation:

$$y_s = 1.57 \times 10^{-4} \frac{\lambda \sum \dot{v}_i D_i \Delta t_i}{M_{loss}}$$

where the summation shall be taken over all combustion test data scans.

**6.5.2** The volumetric flow rate in the test section duct during the combustion test shall be determined from the following equation:

$$\dot{v} = A_d K \frac{\sqrt{2 \Delta p_m T_d / 353}}{\sqrt{P_{atm} / 101,000}}$$

**6.5.3** The extinction coefficient in the test section duct during the combustion test shall be determined from the following equation:

$$D = \frac{\ln(I_a/I)}{L}$$

### 6.6 Convective Heat Release Rate.

**6.6.1** The convective heat release rate shall be determined from the following equation:

$$\begin{aligned} \dot{Q}_c &= m_d c_p (T_d - T_a) \\ &= A_d K \left( \frac{P_{atm}}{101,000} \right) \left[ 2 \left( \frac{353 p_m}{T_d} \right) \right] c_p (T_d - T_a) \end{aligned}$$

where all terms in this equation shall be evaluated from combustion test data scans.

**6.6.2** The gas specific heat shall be corrected for temperature by the following equation:

$$c_p = 1.00 + 1.34 \left( 10^{-4} T_d - \frac{2590}{T_d^2} \right)$$

## Chapter 7 Report

**7.1 General Test Description and Ignition Test.** The following information shall be provided in a test report:

- (1) Specimen identification code or number
- (2) Manufacturer or name of organization submitting specimen
- (3) Date of test
- (4) Operator of apparatus
- (5) Composition or generic identification of specimen
- (6) Specimen thickness and dimensions of specimen surface exposed to infrared heaters (mm)
- (7) Specimen mass (kg)
- (8) Specimen orientation, specimen holder, and description of special mounting procedures
- (9) Room temperature ( $^{\circ}\text{C}$ ) and relative humidity (percent)

- (10) Radiant flux from infrared heating system applied to test specimen ( $\text{kW}/\text{m}^2$ )
- (11) Time when vapors are first observed coming from the test specimen (sec)
- (12) Time at which there is sustained flaming (sec)
- (13) Thermal response parameter ( $\text{kW} \cdot \text{sec}^{-1/2}/\text{m}^2$ )
- (14) Critical heat flux ( $\text{kW}/\text{m}^2$ )
- (15) Additional observations (including times of transitory flaming, flashing, or melting)

**7.2 Combustion Test.** In addition to the information in Section 7.1(1) through (15), the report shall include the following information:

- (1) Chemical and convective heat release rates per unit exposed area of specimen ( $\text{kW}/\text{m}^2$ )
- (2) Generation rates of carbon monoxide and carbon dioxide (kg/sec)
- (3) Effective heat of combustion (kJ/kg)
- (4) Smoke yield values corresponding to wavelengths of 457.9, 632.8, and 1064.0 nm (–)
- (5) Specimen mass remaining after test (kg)
- (6) Specimen mass loss rate (kg/sec)
- (7) Number of replicate specimens tested under the same conditions

**7.3 Fire Propagation Test.** In addition to the information in Sections 7.1 and 7.2, the report shall include the following information:

- (1) Chemical heat release rate (kW)
- (2) Chemical heat release rate per exposed width or circumference of specimen (kW/m)
- (3) Flame height (m)
- (4) Thermal response parameter for the specimen, if previously obtained from the ignition test method ( $\text{kW} \cdot \text{sec}^{1/2}/\text{m}^2$ )
- (5) Fire propagation index, calculated using the value in Section 7.3(2) ( $\text{m}^{5/3}/\text{kW}^{2/3} \text{sec}^{1/2}$ )
- (6) Number of replicate specimens tested under the same conditions

## Chapter 8 Referenced Publications

**8.1** The following documents or portions thereof are referenced within this standard as mandatory requirements and shall be considered part of the requirements of this standard. The edition indicated for each referenced mandatory document is the current edition as of the date of the NFPA issuance of this standard. Some of these mandatory documents might also be referenced in this standard for specific informational purposes and, therefore, are also listed in Appendix C.

**8.1.1 NFPA Publication.** National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101.

NFPA 318, *Standard for the Protection of Cleanrooms*, 1998 edition.

## Appendix A Explanatory Material

*Appendix A is not a part of the requirements of this NFPA document but is included for informational purposes only. This appendix contains explanatory material, numbered to correspond with the applicable text paragraphs.*

**A.1.2.1** The test methods described within this document are part of an existing procedure detailed in *Approval Standard for Clean Room Materials*, Class Number 4910, from Factory Mutual Research Corporation.