

NFPA[®]

287

**Standard Test Methods for
Measurement of Flammability of
Materials in Cleanrooms Using
a Fire Propagation Apparatus
(FPA)**

2017



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NFPA® 287

Standard Test Methods for

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

2017 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. It was issued by the Standards Council on November 11, 2016, with an effective date of December 1, 2016, and supersedes all previous editions.

This edition of NFPA 287 was approved as an American National Standard on December 1, 2016.

Origin and Development of NFPA 287

This standard is based on an apparatus developed by Factory Mutual Research Corporation (now FM Global Research) in the mid-1970s. Since then, several organizations have constructed the apparatus from the original FM Global design. 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.

NFPA 287 was developed to address concerns of the Technical Committee for Cleanrooms.

The 2007 edition was a complete revision for compliance with the *Manual of Style for NFPA Technical Committee Documents*. It also contained a new option for an alternative exhaust system (4.9.2 and Annex C) based on testing conducted by FM Global Research.

The 2012 edition was a reconfirmation of the earlier edition with minor editorial changes.

The 2017 edition includes new provisions for smoke damage index, including a new definition and a new equation.

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2017 Edition

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A reference in brackets [] following a section or paragraph indicates material that has been extracted from another NFPA document. As an aid to the user, the complete title and edition of the source documents for extracts in mandatory sections of the document are given in Chapter 2 and those for extracts in informational sections are given in Annex D. Extracted text may be edited for consistency and style and may include the revision of internal paragraph references and other references as appropriate. Requests for interpretations or revisions of extracted text shall be sent to the technical committee responsible for the source document.

Information on referenced publications can be found in Chapter 2 and Annex D.

Chapter 1 Administration

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.

1.1.1.1 The propensity of these materials to support fire propagation, as well as other flammability characteristics, are quantified by means of a fire propagation apparatus.

1.1.1.2 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.

1.2.1.1 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.

1.2.1.2 The fire propagation apparatus is also designed to obtain laboratory measurements of generation rates of fire products (CO_2 , 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 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 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.

1.2.3.1 This methodology consists of the correlation of flammability indices resulting from the test methods with corresponding characteristics measured during real-scale fire propagation experiments.

1.2.3.2 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) and smoke damage index (S_d).

1.2.3.3 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 This standard is composed of three separate test methods that shall be used in conjunction with a fire propagation apparatus as follows:

- (1) 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 kW/m².
- (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.
- (3) 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 kW/m² and a pilot flame.

1.2.4.1* The ignition test method shall be used to determine the TRP and CHF of horizontal specimens.

1.2.4.1.1 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.

1.2.4.1.2 The CHF shall be determined from the magnitude of externally applied radiant heat flux below which there is no sustained ignition.

1.2.4.1.3 Measurements also shall be made of the time to initial fuel vaporization.

1.2.4.1.4 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 kW/m² 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 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 laser smoke measuring system (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)

(continues)

I/I_a	= ratio of light intensity measured by laser smoke measuring system 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 laser smoke measuring system 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)
S_I	= smoke damage index (m ^{5/3} /kW ^{2/3} sec ^{1/2})
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 · sec ^{1/2} /m ²)
t	= time (sec)
Δt	= 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 (–)
<i>Superscripts</i>	
$\cdot$	= per unit time (sec ⁻¹)
0	= average value before ignition of the specimen
<i>Subscripts</i>	
d	= test section duct

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

Chapter 2 Referenced Publications

2.1 General. The documents or portions thereof listed in this chapter are referenced within this standard and shall be considered part of the requirements of this document.

2.2 NFPA Publications. (Reserved)

2.3 Other Publications.

2.3.1 ASTM Publications. ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959.

ASTM E1354, *Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter*, 2016.

2.3.2 Other Publications.

Merriam-Webster's Collegiate Dictionary, 11th edition, Merriam-Webster, Inc., Springfield, MA, 2003.

Newman, J. S., and J. Steciak, "Characterization of Particulates from Diffusion Flames." *Combustion and Flame*, 67: 55, 1987.

2.4 References for Extracts in Mandatory Sections.

NFPA 289, *Standard Method of Fire Test for Individual Fuel Packages*, 2013 edition.

NFPA 318, *Standard for the Protection of Semiconductor Fabrication Facilities*, 2015 edition.

Chapter 3 Definitions

3.1 General. The definitions contained in this chapter shall apply to the terms used in this standard. Where terms are not defined in this chapter or within another chapter, they shall be defined using their ordinarily accepted meanings within the context in which they are used. *Merriam-Webster's Collegiate Dictionary*, 11th edition, shall be the source for the ordinarily accepted meaning.

3.2 NFPA Official Definitions.

3.2.1 Shall. Indicates a mandatory requirement.

3.2.2 Standard. An NFPA Standard, the main text of which contains only mandatory provisions using the word "shall" to indicate requirements and that is in a form generally suitable for mandatory reference by another standard or code or for adoption into law. Nonmandatory provisions are not to be considered a part of the requirements of a standard and shall be located in an appendix, annex, footnote, informational note, or other means as permitted in the NFPA Manuals of Style. When used in a generic sense, such as in the phrase "standards development process" or "standards development activities," the term "standards" includes all NFPA Standards, including Codes, Standards, Recommended Practices, and Guides.

3.3 General Definitions.

3.3.1 Cleanroom. A room in which the concentration of airborne particles is controlled to specified limits, including areas below the raised floor and above the ceiling grid if these areas are part of the air path and within the rated construction. [318, 2015]

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

3.3.3 Effective Heat of Combustion (EHC). The measured heat release divided by the mass loss for a specified time period. [289, 2013]

3.3.4 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.

3.3.5 Smoke Damage Index (S_f). An indicator of the smoke contamination of the environment during fire propagation.

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

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

Chapter 4 Test Apparatus

4.1 General.

4.1.1 Dimensions.

4.1.1.1 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.

4.1.1.2 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.

4.1.2 The apparatus shall consist of the following components, shown in Figure 4.1.2: 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.

4.2 Infrared Heating System.

4.2.1* 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/m² of radiant flux in front of the quartz window that covers the lamps.

4.2.1.1 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.

4.2.1.2 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.

4.2.2 Power Controller.

4.2.2.1 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.

4.2.2.2 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.

4.3 Load Cell System.

4.3.1 The load cell system, shown in Figure 4.3.1(a) and Figure 4.3.1(b), shall consist of a load cell, which shall have an accuracy of 0.1 g and a measuring range of 0 g 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.

4.3.2* The stainless steel shaft shall incorporate, at the lower end, a threaded adjustment rod.

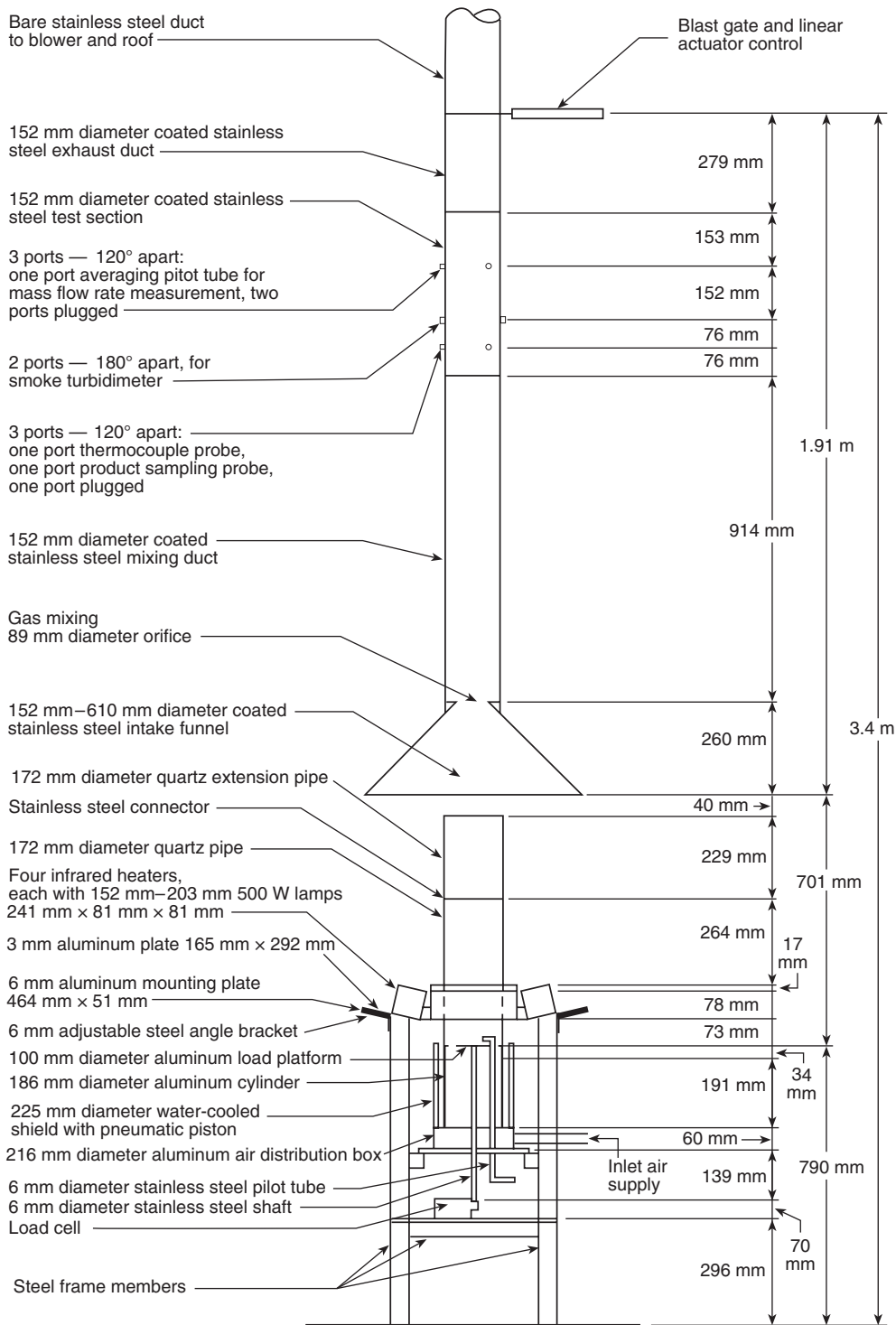


FIGURE 4.1.2 Main View of Apparatus.

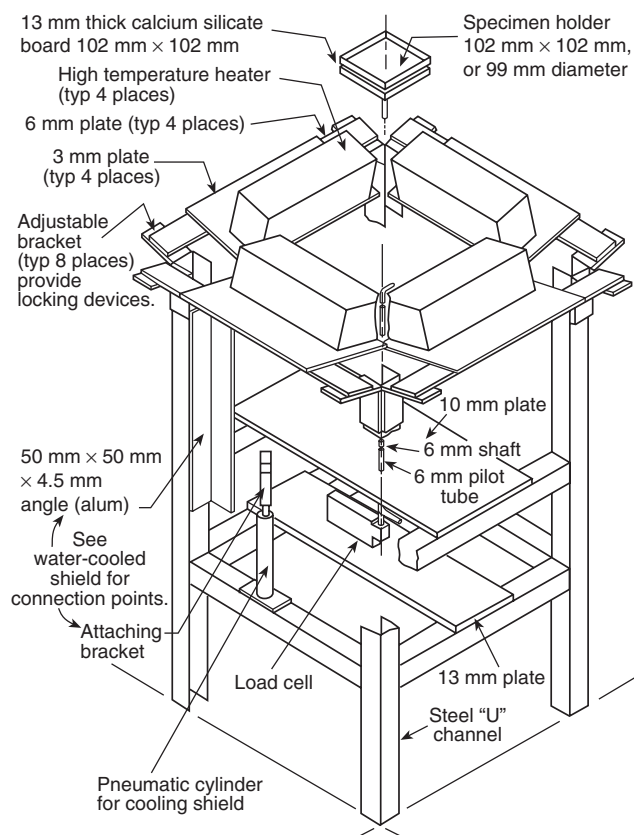


FIGURE 4.3.1(a) Exploded View of Specimen Mounting.

4.4 Ignition Pilot Flame. The ignition pilot shall consist of an ethylene-air 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.

4.4.1 The horizontal section of the tube shall contain a four-hole ceramic insert to produce a stable flame and prevent flashback.

4.4.2 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 Figure 4.3.1(a) and Figure 4.3.1(b).

4.5 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.

4.6 Gas Analysis System.

4.6.1 The gas-sampling arrangement, as shown in Figure 4.6.1, shall consist of a sampling probe in the test section duct, a plastic filter with a pore size of 5 microns 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, CO₂, O₂, and hydrocarbon gas analyzers.

4.6.1.1 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.

4.6.1.2 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.

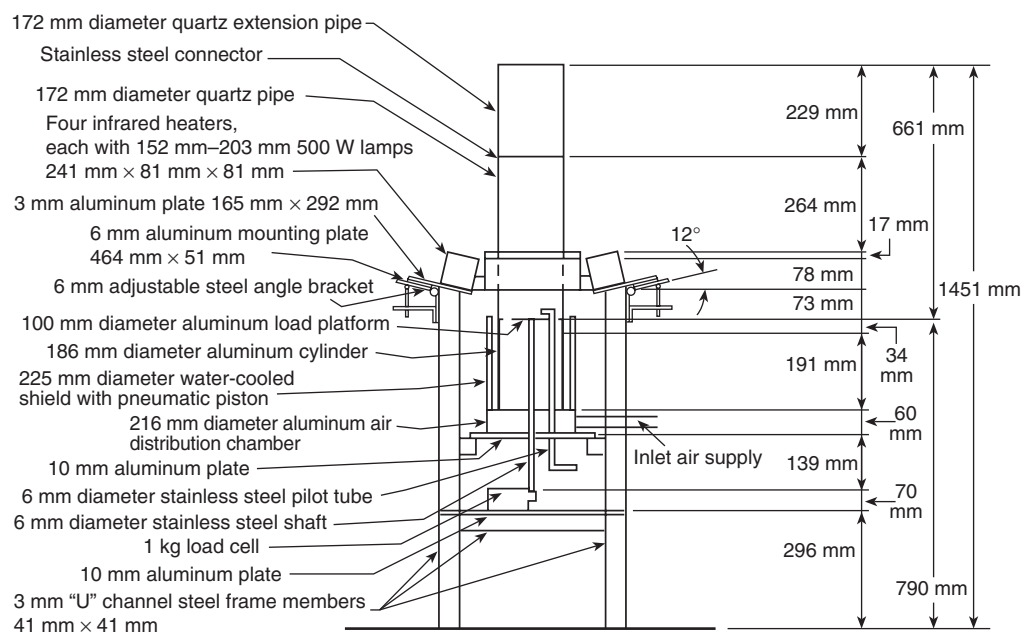


FIGURE 4.3.1(b) Main View of Specimen Mounting.

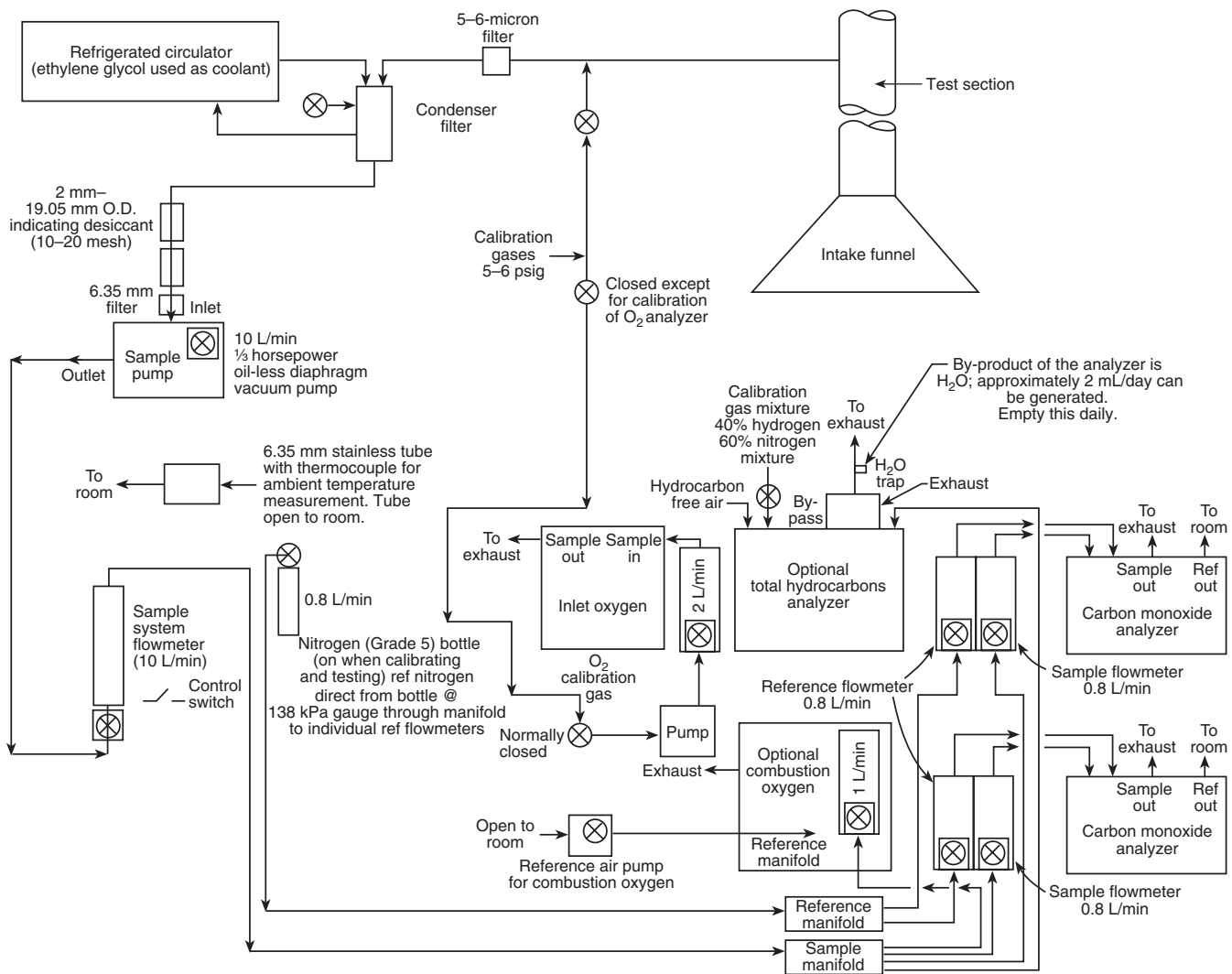


FIGURE 4.6.1 Flow Diagram of Gas-Sampling System.

4.6.2 The carbon dioxide analyzer shall permit measurements from 0 ppm to 15,000 ppm, and the carbon monoxide analyzer shall permit measurements from 0 ppm to 500 ppm concentration levels.

4.6.2.1 Drift shall be not more than ± 1 percent of full scale over a 24-hour period.

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

4.6.3 The inlet-air oxygen analyzer shall have a 10 percent to 90 percent of full-scale response time of 1 second or less, an accuracy of 1 percent of full scale, a drift of not more than ± 50 ppm O₂ over one-half hour, and a range of 0 percent to 50 percent.

4.6.4 An additional oxygen analyzer shall be permitted to measure the depletion of oxygen in the combustion products.

4.6.4.1 This analyzer shall have the same specifications as the inlet-air analyzer but shall have a concentration range of 19 percent to 21 percent.

4.6.4.2 A hydrocarbon gas analyzer shall be permitted to determine the total gaseous hydrocarbon concentration in the combustion products.

4.6.4.3 This analyzer shall employ the flame ionization method of detection, have a 10 percent to 90 percent of full-scale response time of 1 second or less, and have multiple ranges to permit measurements from a full scale of 10 ppm methane equivalent to 10,000 ppm.

4.7 Combustion Air Distribution System.

4.7.1* The aluminum air distribution chamber, shown in Figure 4.7.1, shall contain eight discharge tubes arranged in a circle of 165 mm I.D.